HOW TO UNDERSTAND THE WORKINGS OF RADIO CONTROL

By:
Roger Carignan

This article resulted from a workshop hosted by a member of our R/C model club, the 495th R/C Squadron. I was asked to make a presentation "in simple terms" on the workings of our radio systems. The modelers attending this workshop comprised some newcomers to the hobby as well as some "seasoned" members that were interested in learning how these unique electronic marvels work.

I have limited the article scope by not covering historical development of R/C, recent state-of the art advancements, or extensive component level details.

THE TRANSMITTER

A transmitter is a generator of an alternating voltage. Transmission of this signal through space occurs when connected to a matching antenna. A quarter-wavelength antenna at R/C frequencies is about 3.4 feet long; at 60 Hz power line frequency, nearly 800 miles. One Hz is one cycle per second.

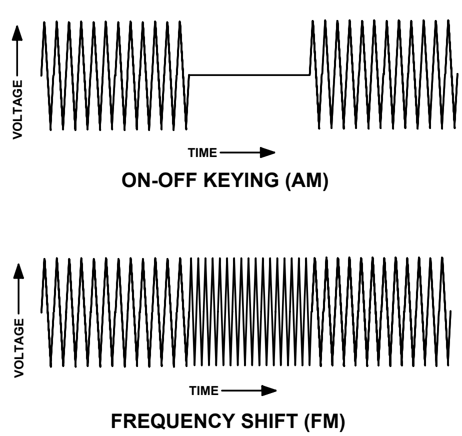
This signal, by itself, cannot send information except to indicate there is a radiation source and it is coming from some point (a beacon). This unchanging signal at radio frequencies is the RF carrier.

In order to transmit information, some characteristic of the transmitted signal must change; this is modulation. Modulation can be in the form of on-off switching (keying) of the signal or changing its frequency; see figure 1.

Whether the modulation scheme is either amplitude (AM) or frequency (FM), the method of transmitting control information is the same; i.e. modulating pulses that determine control information causes either an amplitude or a frequency change in the RF carrier. AM and FM are the types of modulation commonly used in model radio control.

Terms that we read in descriptions of radio control such as PPM (pulse position modulation) and PCM (pulse code modulation) are not really methods of modulation but methods of transmitting the control signals; PPM and PCM transmitters use amplitude or frequency modulation.

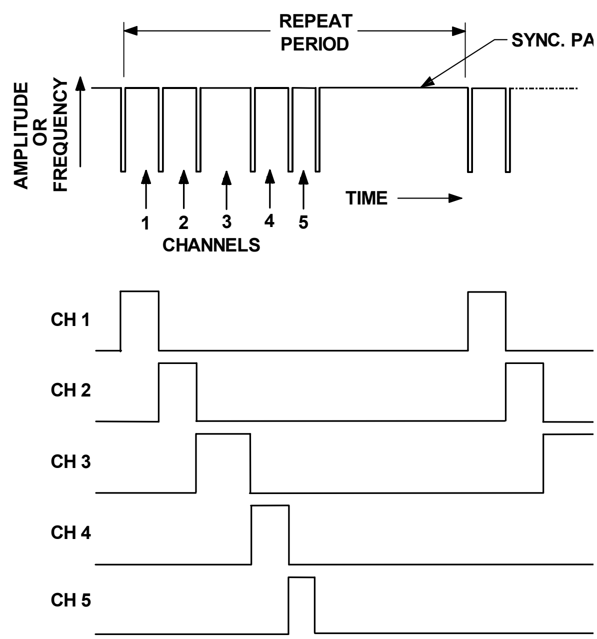
FIGURE 1
TWO TYPES OF MODULATION FOR R/C



What is correctly stated in these terms is the "P" for pulse. All control information is sent in the form of either discrete on-off of the RF amplitude in the case of AM or a step shift of frequency in the case of FM.

The first multi-channel digital R/C systems, and most of today's, utilize a series of pulses to define the controlling signals for each servo channel. Figure 2 depicts a typical train of pulses from a five-channel transmitter; the total number of pulses in the train is one more than the number of control channels.

FIGURE 2
TYPICAL PPM TRANSMITTER PULSE TRAIN



SERVO SIGNAL PULSES

The train of pulses is followed by a longer period; this is to identify which pulse is the start of the first channel and is called the synchronization pause or sync-pause for short.

In PPM systems, each pulse has a length in time of about a quarter millisecond (mS). Spacing between the start of each pulse can vary between one and two mS and defines the pulse width sent to each servo channel. Movement of the transmitter's controls change the position in time of the transmitted pulses and result in change of the respective servo control pulses. Since the pulse positions change to effect servo control, this is commonly called PPM or pulse position modulation.

The particular settings depicted in figure 2 show channels 1,2, and 4 at neutral, channel 3 at maximum and channel 5 at minimum pulse widths. This may be a snapshot in time where the positions of aileron, elevator and rudder are at neutral, the throttle is at maximum and the landing gear or flaps are at minimum.

The particular control function that each channel controls is determined by the transmitter manufacturer and varies among several brands of radios.

Each pulse train repeats at about 50 times per second. Figure 3a is a simplified block diagram of a typical R/C transmitter. Most of today's transmitters use potentiometers, a resistor with a moveable tap point, attached to each channel's control. These vary the voltage applied to the encoder's input for each channel. The encoder converts these voltages into time delays that change the position of each pulse in the train commensurate with the controlled channel. The encoder's signal output drives the modulator (AM or FM) and the modulated signal with encoding is amplified and applied to the antenna for transmission.

FIGURE 3A
R/C TRANSMITTER BLOCK DIAGRAM

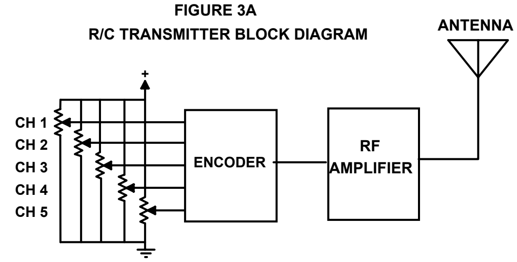
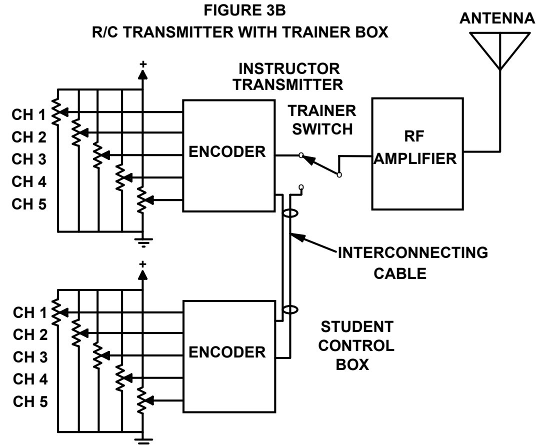


FIGURE 3B
R/C TRANSMITTER WITH TRAINER BOX



From the simplest to the most sophisticated, so-called computer, transmitters, the block diagram of figure 3a still applies; the difference is in the encoder's complexity. In computer radios, processing of the control inputs allow many combinations of servo travel adjustment and neutral position settings as well as various mixing options between the controls. Many of these radios also have setup memories for saving several model configurations.

PCM transmitters have encoders that convert the control inputs to a binary number that is sent to the modulator as a series of pulses. This binary number has all the information needed to define each of the servo channel's properties. The receiver decodes this information and sends the appropriate servo pulse width to each servo.

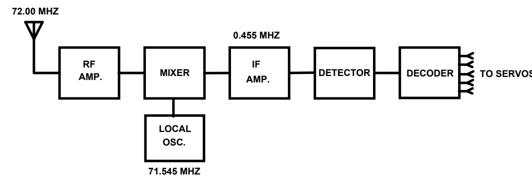
Figure 3b shows how a "Buddy Box" trainer function operates. The trainer control box has its encoder output connected through a cable and to a switch in the master transmitter. When the instructor holds the trainer switch on, the students encoder output connects to the master transmitter's modulator thus controlling the model. Upon release of the trainer switch, the instructor regains control.

THE RECEIVER

Signals from the transmitter excite the receiver's input through the receiver's antenna. Receivers have means of providing frequency selectivity in order to reject signals that are in adjacent bands. This selectivity is typically in the form of resonant circuits tuned to the received frequency.

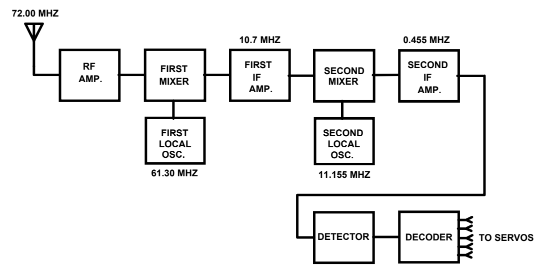
To achieve high receiver gain without oscillation due to feedback from the later amplifier stages, a superheterodyne receiver technique is used. This type receiver uses a local oscillator to generate a signal that mixes with the incoming signal to produce sum and difference frequencies between the incoming and local oscillator frequencies. Figure 4a shows a block diagram of a single conversion receiver. For our R/C receivers, resonant crystals control the local oscillator frequency. A tuned circuit that follows the mixer selects the lower frequency output of the mixer; this is called the intermediate frequency (IF) and is typically 455 kHz (0.455 MHz).

FIGURE 4a
SINGLE CONVERSION RECEIVER



Another important advantage of the surperheterodyne receiver is improved selectivity. Since the bandwidth of a tuned circuit relates to its center frequency, use of a lower intermediate frequency provides an inherent narrow-banding proportional to the ratio of the IF to the received frequency.

FIGURE 4b
DOUBLE CONVERSION RECEIVER



One disadvantage of such a low IF is that the receiver may detect what is called the image frequency that is located exactly the intermediate frequency on the other side of the local oscillator frequency. For example, if the local oscillator is 71.545 MHz and the IF is 0.455 MHz, frequencies of 72.000 and 71.090 will be detected unless a selective circuit suppresses the unwanted signal. Single conversion receivers must have very selective receive frequency circuits to reduce the image frequency response.

Dual conversion receivers correct the problem of response to image frequencies. Figure 4b shows a block diagram of a dual conversion receiver. In these receivers, two local oscillators and two mixers are used. The first mixer uses a local oscillator frequency to provide an IF of typically 10.7 MHz. Since the image frequency of this mixer is 10.7 MHz away from the local oscillator, the input selective circuits are much more effective in reducing image frequency response. A second local oscillator and mixer follow the first mixer; this typically provides a 455 kHz IF with its' inherent narrow banding characteristics.

Following the last IF stage, a detector (either AM or FM) converts the modulation to a signal that replicates the transmitter's encoder output to the modulator previously described.

A decoder circuit in the receiver follows the detector. This is typically an integrated circuit microcontroller specifically designed to convert the detected receiver signal into the individual signal pulses for each servo channel.

THE SERVOS

Servos are the muscle of our systems and perform a function similar to how a human pilot moves the control surfaces in a full-sized aircraft. Each servo control channel of the system provides dedicated control of specific aircraft axes of movement or other function such as throttle (speed) control.

Mechanics of servos are not complex and comprise a DC electric motor, gear reduction, and either a rotary arm or linear output.

As such, operating the servo motor would cause the output to travel to its mechanical stop. The motor would continue to draw current until disconnected. Reversing the motor's polarity would cause output arm motion in the opposite direction to its other mechanical stop.

Each servo receives an input signal pulse width that can vary from one to two milliseconds; a pulse width of 1.5 milliseconds is the servo's neutral position. These values will change to some degree by the transmitter's settings of servo travel end points and neutral trim.

Proportional control of the servo's output requires the following:

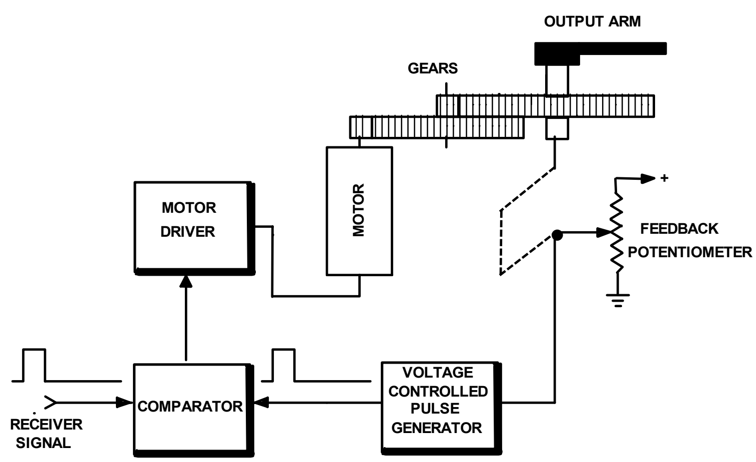
1) A signal indicating the objective output arm position
2) Some indication of the actual output arm position
3) A method of determining the error between 1 and 2 and applying a voltage to the motor of the proper polarity to reduce the error.

Figure 5 shows a simplified block diagram of a typical servo.

The receiver's signal input to the servo is a pulse that typically varies between one and two milliseconds. This satisfies the first requirement in 1) above.

The servo's output arm connects to a potentiometer that supplies a voltage to a voltage controlled pulse generator; as the output arm changes position, the generator's is output pulse width also changes. This pulse width is an indication of the servo arm's position; this satisfies the requirement in 2) above.

FIGURE 5
SERVO BLOCK DIAGRAM



The comparator circuit compares pulses from the receiver and the voltage controlled pulse generator and provides either a positive or a negative output depending on whether the signal pulse width is larger or smaller than the position generator's output pulse. Application of this error voltage to the motor driver circuit causes the motor to turn in a direction that will minimize the error. When both pulse widths are the same, the motor receives no voltage and the output arm position has reached the position indicated by the receiver servo signal's pulse width.

The comparator circuit also implements a "deadband" function that prevents servo jitter and hunting. This is a range over which differences between the input and reference signals will not cause motor operation. When the signal differences exceed this "deadband" range, drive to the motor occurs.

More sophisticated servo circuits, using a modern microcontroller, eliminate the voltage controlled pulse generator and replace it with an analog to

digital function. Measurement of the input signal's pulse width, compared with the potentiometer voltage value determines the motor control signal polarity.

These "digital' servos also have an advantage in providing a true step input to the motor; it is either fully on or off. With older design "analog" servos described above, the comparator output is a short pulse. This pulse repeats approximately every 20 milliseconds and is especially short at small differences between the two pulses. This represents a small duty cycle (the percentage of on-time); the comparator output therefore employs a pulse stretcher that increases the duty cycle to the motor. However, at small deviations between signal and reference pulses, the pulse stretcher cannot maintain the required drive voltage and the motor receives pulses of voltage that can be heard as buzzing when the servo is driving a load. The result is that at small deviations from the objective, the servo cannot maintain its holding force and the servo arm will deflect from its objective position until sufficient current to the motor occurs.

Servos with digital comparators provide full current to the motor whenever the input signal is outside the deadband range thereby providing more accurate positioning under mechanical load.

CONCLUSION

Today's R/C radios have reached a degree of sophistication and reliability undreamed of in the beginning days of radio control modeling. They have become the modeler's "Plug-and-Play" component. Hopefully, for many, this article has provided some insight into how R/C systems work.

Roger Carignan
39 Glen Road
Wilmington, MA 01887
rogercar@gis.net