

The RC Nicad Battery
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How the RC Radio Works Chapter I

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For those of us who go back awhile, the RC systems we now have available to us are far more reliable than that equipment used in the 1960's era. Your editors first RC system was a Galloping Ghost system that used a commercial Galloping Ghost servo, along with my drivers and Radio System. For those who want to know what a Galloping Ghost system was, you really don't want to know.

We've progressed through many revisions over the years, from the wide band RC systems, to the narrow band RC systems, now we've got the Spektrum and Futaba 2.4 Ghz radios.

These radio systems all have something in common, something that has caused a lot of loss of model control and crashes over the past 30-40 systems. That would be the Nicad Battery. Now, we've got the Nickel Hydride batteries, and Lithium or Lipo batteries.

Personal history, your editor works for a company that manufactures circuit breaker controls for the high voltage substations that exist all over the place. Some of our older controls used a 24 Volt, 1.2 Amp Hour Nicad battery certified to operate between minus 40 degrees to plus 140 degrees F. We manufactured some 50,000 of these controls over a period of 30 years, and your editor was directly involved in testing many of their Nicad batteries over this same period of time. I've cut open a number of these NiCad's to examine what happened inside them.

How the RC Radio Works Chapter II

Battery Information

OK, we've all heard battery terms such as volts, amps, milliamps, milliamp hours, watt hours, internal battery resistance, and the list goes on. What is all this stuff??

Most everything we deal with has parallels in other fields. In the electronic world, battery voltage is directly comparable to water pressure in your house or apartment. Battery current is directly comparable to the rate of water flow out of a faucet.

We measure battery "Pressure" in a term called voltage. Typical values, a Nicad cell puts out 1.2 Volts **Direct Current**, a typical Alkaline cell puts out 1.5 Volts DC, a lead acid cell puts out about 2 volts DC, a Lipo Cell puts out about 3.7 Volts DC.

For the most part, one cell is not good for much, unless you are trying to run a battery operated clock. These cells can be stacked on top of one another, a term called putting them in series. So, for your typical RC receiver pack, we have four cells in series. Their combined voltage does add up, so 1.2 volts per cell, multiplied by 4 results in the nominal 4.8 volts per cell we've all observed in our equipment. Same goes for the transmitter pack that uses 8 cells. Their typical voltage is on the order of 9.6 Volts DC, or simply 9.6 VDC.

To simplify, go out and buy 100 fifty five gallon barrows, fill them with water, a place them all side by side, and connect them all to a big piece of pipe. That's configuring the barrows in parallel. You will not get enough pressure to put out a fire with a hose and nozzle, but since they are in "parallel" you could run enough water out to flood your back yard.

Now, take those 100 barrows, and stack them on top of one another. Connect the bottom of the top barrow to the top of the next barrow under it, and repeat for all 100 barrows. That's placing the barrows in series. The bottom barrow now has a substantial amount of pressure, and can be used with a hose and nozzle. The same applies to cells and batteries made from cells. These cells can be placed in parallel, where the output voltage would be the same as one cell, but at higher current values. (Putting Nicad batteries in parallel is not a good idea. Due to technical reasons, they do not evenly share loads.) Cleaning out your local hobby shop by buying 100 9 volt NiCad packs and placing them in parallel would still result in 9 volts. It would not be dangerous, other than shorting them out would probably melt anything in their path. However, putting them in SERIES would be very dangerous, since their output voltage would be 900 Volts DC. That's about 1/2 of what is used in an electric chair. (Direct Current, as compared to Alternating Current found in your house, but that's another subject)

Now, a voltage of 900 volts can be very lethal. You'd better be handling them with electric power employees line men's insulated rubber gloves to stay alive. But on the other hand, voltage alone is not dangerous. The static sparks you get just walking on a carpet can easily exceed 10,000 volts, but has little power behind it, except for frying electronic parts. Which is why you should be wearing a static wrist strap when working inside your computers and so on.

As just indicated, the battery voltage has absolutely no relation to its capabilities of putting out POWER. Going back to water pressure, you can take a gallon of water, place it on your desk two feet off the floor, run a hose from the bucket to the floor and measure its pressure. It will be something like one pound per square inch, or one PSI. Take that same bucket of water, take it to the top of the Sears Tower in Chicago, run a hose down the side of the building, you will measure a very substantial increase in pressure, something on the order of 700 PSI at ground level. If you use a hose of 10/1000 inch diameter, good luck in trying to fill a glass of water with it. Now, take that same 10/1000 hose, and change it to a one inch pipe. Water coming out of a one inch pipe at 700 PSI could hurt someone.

Now, that gallon of water raised to a level of some 1500 feet in the air represents a certain level of potential energy when it is allowed to drop to street level. Note that it is nothing, unless it is allowed to move from the top of the building downwards. Once this gallon bucket of water moves vertically, it performs work. This work can be valued as Foot Pounds, Inch ounces, Mile tons, watts, Kilowatts (1000 Watts) or what ever. The amount of work this gallon of water can perform is related to its pressure, and the weight of the water that is moved. It does not matter if the water flows through the 10/1000 pipe, or the one inch pipe, the total energy is the same when this gallon drains to street level.

Something else is happening here. The RATE of water flow between the 10/1000 pipe, and the one inch pipe would be very different. Lets put a nozzle on the bottom of the pipe, say 1/8 inch diameter. This 1/8 nozzle will set the RATE of water flow for the one inch pipe. This would be measured in gallons per hour, gallons per second, liters per day, whatever. Running that 1/8 nozzle on the end of the 10/1000 pipe would be rather disappointing. You couldn't wash your hands with it. Washing your hands with the nozzle on the one inch pipe could result in a trip the emergency room.

So, how much Power (Foot pounds per second, or horsepower, or watts, or Kilowatts) is involved?? It would be the water PSI multiplied by the Rate of water flow. How much Energy is involved?? It would be the PSI multiplied by GPH multiplied by the total **time** the water is flowing.

So what?? Again, this stuff has a direct correlation to our batteries. Take that PSI value, change it to Volts. Take that rate of water flow, call it Amperes. Take that Horsepower, call it Watts. Take that Total Energy, call it Watt-hours. (You've probably found the term Kilowatt Hours on your electric bill. One KWH represents the energy provided by a 1.34 Horsepower motor running at full load for one hour. More useless info, it takes about one pound of coal for the Oak Creek Power Plant to generate one Kilowatt Hour for your house. If you've used 200 Kilowatt Hours for the month, that indicates WE Energies burned 200 pounds of coal to generate the 200 KWH.) .

So, just what is that 600 MaHr rating on your RC radio packs? It is exactly what it states, the battery is capable of putting out a current rate of 600 Milliamperes (0.6 Amps) for one hour, or 60 Ma (0.06 Amps)

for 10 hours, or 6 Ma (0.006 Amps) for 100 hours. Things start to fall apart when we try to run 6000 Milliamps (6 Amps) for 0.1 hours. Remember that 10/1000 hose down the side of the Sears tower. Much of the batteries total energy will be lost inside the battery creating heat, perhaps to the point of damaging the battery or if it's Lipo, damaging your house.

And, last, power is the voltage multiplied by the amperes, which the exact formula for watts. So, if you discharge your 600 MaHr pack in one hour, you are discharging it at 600 Milliampere (0.6 Amps). And, if you multiply this 600 MaHr (0.6 Amps) times voltage of 4.8 Volts Direct Current, you get 2.88 watts. Divide this by number of watts per horsepower of 746, you get 2.88 divided by 746 or 0.0038 horsepower.

A typical electric motor such as the Hacker A50 Series Brushless motor is rated at 45 Amperes at 24 Volts DC. Lets see, 45 Amps times 24 Volts equals 1080 watts, divide this by 746 (746 Watts equals One Horsepower) equals 1.44 horsepower. These motors are about 85 to 90% efficient, so the shaft horsepower is on the order of 1.3 horsepower. If we borrowed three of those 9.6 volt transmitter Nicad packs, put them in series, and try to run that Hacker motor with it, we run into the problem of the 10/1000 hose down the side of the Sears tower. The motor would turn over, but if you tried to load the motor down, the Nicad packs could not put out the required 45 Amperes. It would also likely overheat or melt the transmitter Nicad packs.

For those following the electric models, some of these motors are rated for 100 Amperes at 24 volts and higher. This is enough horsepower to turn over your Chevy 350 cu in V8. Our hobby has changed over the years.

Hopefully this has shed some light on those power sources we all take for granted on our radio equipment.

How the RC Radio Works Chapter III

The following comments are one man's opinion. You may or may not agree with them.

Nicad batteries, outside of broken wires or internal damage are extremely reliable, and predictable, if you know how to verify proper function of these devices. If these Nicad batteries are nearing the end of their life, they will give plenty of warning before you loose a model because of them.

The Nicad Battery used in the transmitter seldom gives problems due to two reasons. First, most transmitters have a built in meter that indicates condition of the battery. Second, these transmitters place a very constant discharge load on the batteries. This is very different from the Nicad battery used in your model airplane. The load in these models can vary from very low levels in a Sailplane, to very high levels in a gasoline powered acrobatic model. Significant differences will even exist between a gasoline powered ¼ scale Piper Cub, and a very acrobatic gasoline powered YAK. And, this battery discharge level will vary even during the flight of one of these models.

I've used several rules on the use of these batteries over the years, and have listed them below:

1. A voltage check of a Nicad battery should **NEVER, NEVER, NEVER** be used to determine current state of charge of a Nicad battery.
2. A voltage check of a Nicad battery should **NEVER, NEVER, NEVER** be used to determine current state of charge of a Nicad battery. (Yeah, this is important.)
3. Never use more than 50% of a Nicad batteries total capacity during any particular flying session.
4. Always conduct a "Shelf Life" test of a Nicad battery at least once a year.
5. All ways conduct a battery capacity test at least twice a year with a commercial battery cyclor
6. Never short a Nicad battery.
7. Never directly parallel two Nicad batteries for extra capacity.
8. Never Ever allow one of the model servos to be stalled at either end of their travel.
9. If a Nicad cell has ever "Vented", scrap the entire battery, do not use it.
10. Be very leery of a receiver battery that has been involved in a serious crash. The individual cells are spot welded together under the shrink tubing. A crash can damage the spot welds, leaving the jumper straps just resting against the cell, rather than spot welded to it. At the very minimum,

remove the shrink wrap and individually check the cells for broken welds, and dented cells. Its just safer to replace it.

Following these rules will significantly reduce the chances of loosing your model due to battery failure. OK, so what is this stuff??? Lets cover them in order.

Item 1.

It can very easily be shown that the battery voltage of a Nicad Cell has absolutely no relation to its total charge level. What is needed is a fully charged Nicad battery, and a battery discharge device that records voltage while the battery is being discharged. Your editor built a Microcontroller device that does exactly that, and is able to discharge anywhere from one cell to 30 cell Nicad packs at discharge levels between zero and two amperes. Using this set up, a standard 600 MaHr Nicad Pack was discharged down to 1.05 volts per cell, or 4.2 volts for the entire pack. This 4.2 volts indicates a totally discharged battery. Next, these voltage readings were plotted in Excel. Then the battery was given a charge of exactly 60 MaHr. The battery test was repeated with the same exact set up. At the end of this 60 Milliamper charge, 10% of battery capacity, the battery measured one percent less then the when it was fully charged. You could have a 10% charge in a battery and go flying using the voltage measurement test. Guess what happens next. The resulting crash will be blamed on the Nicad battery, not the guy behind the transmitter stick.

Item 2.

Read Item 1.

Item 3.

This is directly the result of the unpredictable loads placed on the receiver's battery pack during a flight. If you can't use the battery voltage, how do you determine what is the maximum number of minutes you can fly on a receiver charge??

Its really fairly simple, the third and forth time you do it. (First time, you might use new words for the editor of this column.)

What's needed? First, you need a Nicad battery. Second, you need one of those Nicad battery cyclers. (They cost a few bucks, but saving just one model will pay for it.) That's about it. Then follow the procedure below:

1. Fully charge the battery.
2. Use the battery cycler, and determine total Milliamper Hour capacity of the battery. Write it down. (I write mine on the battery itself and date it.)
3. Fully charge the battery. (**Do not fly after step two, you've got a dead battery!**)
4. Go fly the model for a reasonable amount of flights.
5. Take the model home, do not charge the Nicad battery.
6. Use the battery cycler again, and determine total Milliamper Hours **LEFT in** the battery. This value left in the battery should exceed 50% of the fully charged value of the battery. Example, say the battery tests at 620 MaHr at full charge. You go fly, test what's left, and find you've got 214 MaHr left. Now, we had 620, we have 214 left, so 620 minus 214 equals 406 MaHr used during your flying session. Dividing 406 by 620 equals 65% of the battery capacity was used during this flying session. Problem, you've violated the 50% rule. Either don't fly as much, or get a Nicad battery with more MaHr.

Item 4.

Shelf life? What is it, how do you test it? Again, you need the battery cycler. Just fully charge the battery, and place it on the shelf for a period of time, 30 days is good. Don't charge it, just leave it. Then determine state of charge of the battery with the battery cycler. It should not have lost more than 5 or 10 percent of capacity. If this battery did not survive the shelf test, you very likely have a cell in the battery pack that has a problem. Do NOT just replace the bad cell, buy a new battery. One bad cell is a sign of more to come. Your editor replaced two batteries because of shelf life problems over the past year. One was in a transmitter, one in a receiver. The receiver battery tested just fine after charging. After three weeks, one cell was down to 1.1 volts, and was virtually dead.

Item 5.

These batteries very seldom fail with no warning. Any problems will usually be found long before it is critical by testing these batteries twice a year with a commercial battery cycler. I run the test on the battery, and mark the date and MaHr capacity directly on the battery with a marker pen.

Item 6.

These batteries are capable of pretty high currents. Shorting them can damage the battery or its wiring.

Item 7.

Never directly parallel Nicad batteries. These Nicad batteries do not share loads and charging very well when paralleled. They have something called negative voltage coefficient, where the voltage may DROP when the cell warms up. Carried to extremes, placing many batteries in parallel can result in some of the batteries discharging into one battery, resulting in thermal run away, destroying the battery. It would also be a fire hazard. Yes, our customers have done this. Worse, paralleling two 600 MaHr batteries may not give you a 1200 MaHr battery. It could actually wind up less than 600 MaHr, after a shelf life test. **Paralleling Nicad Batteries requires special circuitry to isolate one from the other.** Or, just build up a Nicad Pack using larger Nicad cells.

One good Nicad Cell is the Sanyo RC 2400 cell, available at any hobby shop. These cells can put out sufficient current to power just about any type of model. But, DO NOT use the standard 50 Milliampere charger on them. They should be charged at about 250 Milliampere for 15 hours or so.

(Your editor just conducted some tests on several alkaline cells on my battery tester. Was very surprised to find that any good NiHyd cell can out perform the alkalines. The penlight batteries tested only measured 0.95 MaHr when discharged down to 1.1 Volts DC. These alkalines are factory tested down to about 0.9 Volts DC, long after our radios have quit.)

Item 8.

Do not allow servo's to be stalled at either end of their travel. It's easy to hear, they make noise when they are stalled, or are carrying high loads. Stalled servos can discharge a Nicad pack in much less than an hour, again the resulting crash will be blamed on the Nicad pack. Not only that, but a stalled servo will overheat, and may fail, shorting out the battery. Now, you really got problems.

Item 9.

Nicad cells venting. Its pretty hard to cause this type of failure in a Nicad cell. One thing that will do this is severe overcharging of the cells. FYI, these cells are enclosed in a steel jacket with an explosion proof seal at the positive end. During high charging values, the internal pressure can easily exceed 150 PSI, the main reason for the steel jacket. If you connect one of these directly across a car battery, the resulting hundreds of amperes will cause the cells internal PSI pressure to skyrocket, potentially leaving pieces of steel jacket in your hide. These Nicad cells have an internal one shot pressure relief consisting of a sharp point that punctures an internal disk, preventing an explosion. The battery will still work, but will loose internal potassium hydroxide over a period of time, and will fail.

The newer NiHyd Nickel Hydride cells now being used are very similar to the Nicads, and have many of the same rules.

The Lipo Batteries are very different. As indicated previously, discharging them below a certain threshold will damage them permanently. How many of us have accidentally left a receiver switch on overnight, totally discharging the battery? In a Nicad, or NiHyd battery, you just recharge it, test it, and go fly.

If this happens on a LiPo battery, and you don't notice, you've got a crash coming. Again just one persons opinion.

How the RC Radio Works Chapter IV

The magazines have had several articles on the new “Spread Spectrum” radios that use different frequencies for the radio link to the model airplane. Some of us go back to the 1960’s when the CB radio frequencies were used for radio control. I was one of them. Problem with this frequency was anyone talking on a CB radio could and did knock you out of the air. Later, we got some frequencies in the 72 Megahertz (Mhz) frequencies known as “Wide band”. These were both manufactured as either Amplitude Modulated or Frequency Modulated, also known as AM and FM, same technology as the AM and FM radios you have in your car, just different frequencies. Amplitude modulation varies the intensity of the radio signal in step with what ever signal you are trying to send. Our AM RC radios actually turn the radiated signal on and off at a very rapid rate, some 50 times per second whenever the transmitter is turned on. This makes these AM RC transmitters very vulnerable to any other RC transmitter on the same frequency, even if its far away. The other transmitter could just fill in the “Gaps”, resulting in getting shot down.

The original radios designed in the very early 1900’s used AM Modulation. It just so happens a lot of radio “noise” such as lightning, ignition systems, and similar items also produce AM radio frequency noise. You may have noted that AM radio receivers produce static whenever any lightning flashes took place near by.

Later on, a process known as Frequency Modulation was invented that did away with a lot of the problems with AM. One significant benefit of FM was the transmitted signal level was continuous. The RC receiver picks up the strongest signal and ignores any others.

Now we have something known as Spread Spectrum radios, that doesn’t require frequency flags. True Spread Spectrum communications dates back to WW II and “frequency hops” over a number of different frequencies at hundreds of times per second. Newer technology uses a band of frequencies. These signals were extremely difficult to intercept, making them very useful for the military.

The Spread Spectrum RC transmitters currently being advertised first “Listens” to see which frequencies **are not** being used, then selects just **two** unused frequencies and uses them to communicate between your transmitter and model airplane. Now if someone else turns on his Spread Spectrum transmitter, the second transmitter determines that two frequencies are already in use, and finds two other frequencies. This might sound somewhat familiar to a few of us. It’s cell phone technology.

These new Spread Spectrum radios transmit on something called micro-waves. It also happens that nature has a very difficult time generating micro-waves. Lightning doesn’t produce micro-waves, ignition systems do not produce microwaves, metal to metal fittings on your models do not produce microwaves. So in theory, you should not have to worry about these issues on these new radios.

Just to be safe, still check everything for range and interference as usual when using these new radios.

Interesting Internet site covering everything you ever wanted to know about batteries is www.buchmann.ca

How the RC Radio Works Chapter V

Your editor has added a new Spectrum radio to his inventory with three receivers. Very nice. Question, how do they make these antennas so short? And how do they work??? Well, this will get into a little theory on how these things work. The next few newsletters will have a series of articles on what’s happening under the plastic covers of our radio gear, and how it affects us all.

Radio Control Transmitters: A transmitter is something that sends information out into the world. This can be anything from your vocal cords to a vibrating string in a guitar to a radio/television transmitter tower, to the RC transmitter you hold while remotely controlling your models. These items all have something in common. They are transmitting a frequency or various frequencies while being used. What is frequency? Its simply a number of cycles per second of something. It could be sound, could be waves on a lake after a boat goes by, it could be electro-magnetic waves (Huh??)

Sound ranges from about 20 cycles per second to perhaps 20,000 cycles per second. If you send this sound into a microphone and send it to an amplifier, the amplifier will convert the sound to electrical signals that can drive speakers and a lot of other stuff. In fact, if you connect the output of the amplifier to a very long piece of wire you can actually broadcast radio waves. The problem is the antenna would have to be miles in length. It would not work very well. (The military tried doing this exact same thing up North in Wisconsin for communication with submarines.)

If you could locate some super soprano singer that could really hit the high notes (Very high notes!) and could hit 620,000 cycles per second, and send it through a super audio amplifier, in theory at least, you could take WTMJ radio off the air. The antenna's for 620,000 cycles per second can be shorter, but still on the order of 1/3 of a mile. If we move up to the Television radio signals, these broadcast in the same area as our RC transmitters. These signals range in the 50 million cycles per second and higher. Our Radio Control transmitters transmit at 72,000,000 cycles per second. We can use the proper terms for cycles per second, defined as Hertz, for the guy who had a lot to do with what we know about radio a hundred years ago or so. So, our RC transmitters are transmitting at 72,000,000 Hertz, or 72 Mega Hertz. The antenna's for these radios can be considerably shorter, as can be observed by the length of wire for our RC receiver antennas.

What defines the length of the radio antenna? Its directly related to the radio frequency, and of all things, the speed of light. If you take the speed of light in feet per second, and divide it by the radio frequency, you wind up with about how long the antenna should be. The proper antenna length for our RC transmitters is on the order of 13 feet.

These antennas can be $\frac{1}{2}$ wave, $\frac{1}{4}$ wave and so on, making them more useable for our RC equipment. So, what do these new Spektrum radios transmit at? They are running at 2400 Mega Hertz (Also known as 2.4 GigaHertz or 2.4 Ghz), a factor of 33 times higher that what we are currently using for the RC systems.

Now, if we could increase this 2.4 Ghz frequency by about 100,000 times, we would not require a radio. We could see it, it's called visible light. It's all part of the same radio spectrum.

This allows the Spektrum radios to use an antenna about 33 times shorter than the RC equipment we now use. But, why the two antennas???. They call this type of antenna a Dipole antenna. We've seen them before, just look at your TV antenna rabbit ears, or any outside television antenna, they are also di-pole antennas. They've got different length beams to cover the entire channel 2-13 channels

Di-pole antennas are more effective than just a piece of wire. Problem is, they are also more directional than a piece of wire. So, at least for the receiver, just one receiver antenna can result in dead spots depending on the orientation of the receiver antenna and where the transmitter is located. To add to the issue, a large gas engine located between the transmitter and receiver can result in no signal. The quick solution was to provide a second receiver with a second antenna for the Spektrum DFX receiver. Microwaves also have issues with something called polarization. The polarization effect requires the second antenna be rotated by about 90 degrees from the primary antenna for the Spektrum DX7000 receivers.

These microwave radios might be one of the most significant improvements for our hobby in years.

How the RC Radio Works Chapter VI

Well, it had to happen. The May 2007 issue of Fly RC magazine has a very short article on the new Futaba 6EX 2.4 GHZ FFAST radio system. This unit is available as a transmitter/receiver only for about \$220.

Futaba's web page indicates that they have been using this system for industrial purposes for many years, and have just made a version of it available for model RC use.

This system is based on the TRUE Spread Spectrum system where the transmitter and receiver "Frequency hop" over the 80 channels available. This frequency hopping takes place 500 times per second. Under this

type system, the frequency hopping can be in any order. If the frequencies are picked truly at random, having two transmitters on exactly the same frequency hopping frequency sequence at the exact same time would be as difficult as winning the lottery.

What can happen with this type system, is at some particular instance in time, two transmitters could transmit on the same exact frequency at the same exact time. But, due to the nature of frequency hopping, this would only occur for ONE "Hopping" which translates to 0.002 seconds. You'd never notice, and the receiver computer programming would pick this out and ignore it.

I've made a quick comparison between the Futaba system and the Spektrum systems, they are similar in capabilities. The Spektrum transmitter is very similar to the JR system.

As for potential interference between the Futaba system and the Spektrum systems, info on the Internet indicates that this was tested, and no problems were noted.

How the RC Radio Works Chapter VII

More on batteries.

We have new batteries, namely the Lipo batteries that are dominating the electric power source for electric models now days. our editor is rather uncomfortable with Lipo batteries for the critical receiver function. If these batteries are ever discharged to low in voltage, they will lose Amphours capacity. You may not know it until your model crashes.

Something else on Lipo's, various Internet sites indicate that these Lipo's loose about four percent of their capacity per year, even if they are not used. Also, storing them for off season requires special considerations.

Well, something new is out there, and they are being used in Dewalt portable battery operated drills. These cells are a slightly different chemistry composition than the Lipo's, and as a result they have a slightly lower output voltage of 3.4 volts under no load. The various web pages indicate that these cells will put out 3.0 volts each with a 20 ampere load.

After tracking this down, looks like the A123Racing.com web page has the best deal on these cells. Greenfield Hobby now has them in stock. Their rating is 2.3 Amp hours, internal resistance is 0.01 ohms, cell weight is 70 grams, or about 2 ½ ounces. The startling part, is they are rated for a 50 Ampere continuous discharge rate! And even more interesting, some idiots out there are recharging these cells at 30 AMPERES. A123 racing has indicated this is not safe, but people are doing it. So, the bottom line is, you can not safely recharge a Lipo battery in less than an hour without affecting their life. These A123 cells can be recharged in 15 minutes, discharged in 5 minutes, and still have a 1000 charge-discharge lifespan. These cells must be recharged with a charger designed for the slightly lower voltage. The chargers are readily available.

Your editor purchased a four pack of these cells, and assembled them into a battery pack. Net result, these four cells are equivalent in all respects, power ability, voltage out to 10 RC2400 Nicads, at 50% of the weight.

The battery pack was charged, and was given a load test at 20 Amps on my high power resistor load test box. The results I got with a Fluke 87V 0.1 percent accuracy meter was identical to the published literature at A123 racing.

Even more interesting, the A123racing web page has a video of an unnamed Lipo pack test against their A123 cells. This test consists of remotely driving a nail through the cells. The Lipo battery burst into fire as soon as the nail pierced the plastic jacket of the Lipo. Think about a minor crash where the Lipo battery comes loose and is punctured by something.

They did the same thing with the A123 cells. Yes, this would have definitely set off the smoke alarms in your house, but absolutely no fire. And, these cells have a metal jacket, possibly aluminum, with steel tabs laser welded on them to allow easy soldering.

I've purchased two of the Dewalt 36 volt batteries from Ebay, and have built up a battery with 12 cells, six in series, two parallel, or 6S2P configuration. It will be running a Hacker A50 series motor that I've checked with a 16/10 propeller. This combination turns the 16/10 at 6200 RPM, putting out 7.5 pounds thrust with a prop wind speed of about 55 miles per hour. It's going to fly next year. (4-10-08 update, the model is built, powered with a Hacker A50-16S with a 16/12 APC-E prop. It should fly well in 2008.)

How the RC Radio Works Chapter VIII

Just a quick note on the last issue's article on our NiCad batteries. Two battery articles were written, version I and II. The second article cleared up the issue of paralleling NiCad batteries, and pointed out that this is not a good idea. Hard wiring two or more NiCad batteries DIRECTLY in parallel is NEVER a good idea because of negative temperature coefficient characteristics of these types of batteries. However, it is a good idea to have primary/backup battery packs for the more expensive or faster flying models. For this use, commercial battery isolators that are designed for paralleling NiCad batteries must be used.

Many years ago, in 1959 your editor was in college taking his first course in electronics. After the instructor introduced himself, he asked for questions. First question was "Just how do superhetrodyne radios work?" Instructors response, "very nicely, next question?" We did cover this subject in later courses.

But, this column has to start some where, as good as any place to start is the transmitter. A radio transmitter is a device that sends out radio waves in some form or other from the transmitter. These radio wave signals were described in a previous newsletter. Basic review, these radio signals can range over a very wide range of frequencies, from audio frequencies, to 1,000,000 Hertz, or one megahertz (cycles per second) for the commercial AM band, to 100 megahertz for the commercial FM band. In between these signals is the commercial television band that ranges from some 54 Mhz to something like 500 Mhz for the UHF frequencies such as channel 58. If you've looked at the back of your transmitter, these operate at 72 Mhz frequency. Now we've got the new Spektrum radios that operate at 2400 Mhz frequencies. In fact, if you could increase the Spektrum frequency by some where around 100,000 times, you would not require a radio. You could see it as visible light. It's all part of the electromagnetic spectrum.

Well, what does it take to make a radio transmitter. Not much in fact. You can make one with just a single flashlight cell, and a few feet of wire. Find an AM radio, tune it to some off channel like 600 KHz on the dial. Wrap the wire around the radio, and briefly connect each end of the wire to the plus and minus connections of the flashlight cell. (**BRIEFLY**, you are placing a dead short on the flashlight cell. Just brush the lead back and forth on the flashlight cell. You will hear a "scratching sound through the speaker.")

We have a radio transmitter that fits the legal description. It isn't much, and broadcasts all over the radio dial, quickly verified by changing the radio dial to a different frequency. In fact, this is something like what the smart folks were doing back in the late 1800's with the first realization that man kind could create radio waves.

Oh, by the way, above we mentioned that we must make and break the connection to generate radio waves. Just leaving the wire shorted across the battery generates NO radio signal. This suggests that ALL radio waves are Alternating Current (AC) in nature. Just about everything

around us is AC in nature, right down to the 120 Volts AC 60 cycles per second (Hertz) that feeds the building where we live. When you see battery, a battery by definition is DC, or Direct Current.

Now just how do we transmit on only one frequency???, Resonance, dear reader, resonance. (Next question!)

Ok, Ok, this requires clarification. Resonance is all around us, in many different forms. Even small children use it without knowing it. Resonance is sort of a natural frequency of something. You can put someone on a swing set, and push them at a very specific frequency to get the person to swing back and forth. Just push a little too soon, or a little too late, and the swing set doesn't work. In fact, you could put 500 pounds of cement on the swing set, and get it to swing back and forth with very little effort. If it were not for wind resistance, the effort would be nearly insignificant. Now, wait for the cement to stop swinging, and just apply a continuous push. You won't get very far. (That's DC!)

What are we doing with this swing set? We are dealing with energy, more specifically, energy transfer. The energy stored in the cement is all potential energy when it is at the top of its arc and momentarily stopped. It is all kinetic energy when it is at bottom dead center when it is moving at its fastest speed. The total energy is constant, and is sloshing back and forth between potential energy and kinetic energy as the cement swings back and forth. All that to swing a swing set.

So what?? It so happens that the mechanical world and electrical world have very many things in common. Even many of the mathematical formulas formulas in the mechanical and electrical world are virtually identical.

Now, just what is resonant in the electrical world?? It turns out that you can build a electrical resonant circuit with just a capacitor and inductor. What are capacitors and inductors? Think of a capacitor as two metal plates separated by an air gap. That's it. Think of an inductor as a coil of wire. You connect these two items in parallel, and they will be resonant at some specific electronic frequency.

Take a look at the digital photo below. This is nothing more than two pieces of aluminum, with a coil wired across them. This thing is actually tuned to pickup our RC transmitters.



Speaking of radios. There is something in the real world we live in, that the reliability of devices follows a "Bell Curve". This is a way of saying that a typical product will have "Infantile

failures” first, then work very well during the life of the unit, then have problems near the end of its life due to getting old, you name it.

Well, one of the receivers in my new Spektrum DX7 radios just quit while taxing around the driveway. Everything quit, if the model had been flying, it would have cost my 150% Electrostroke. With 45 years experience of troubleshooting, I traced the problem to the receivers 5 volt bus feeding the servos. A double sided plated through hole wasn't. A quick solder job fixed it. Next, micro-ohm tests were conducted at 6 amps on the two other receivers. No problems were noted. A search of the internet on this issue showed no other problems of this nature.

So, before flying with a new radio, work it on the ground for a few hours. It could save an airplane.

How the RC Radio Works Chapter IX

This series of articles is going to progress through the basics of the RC radios we all use. For those who just “use the radio’s” and don’t care how they work, just ignore this part of the newsletter.

OK, we previously described resonant circuits in electronic equipment. Now, if we take that thing put together with two metal plates and a coil of wire, and briefly connect an alkaline cell across it, and let go, this thing will actually oscillate, extremely briefly, but it will oscillate, at around 72,000,000 cycles per second. We can observe it as a Damped Sine Wave” on an oscilloscope.

OK, what the heck is a damped sine wave??? Back to the swing set. Take the swing set with the 500 pound block of cement, and put a leaky bucket on it, full of black ink. Give the swing set a push, and the bucket will spill ink back and forth from bottom center, to left, back through bottom center to the right and on, and on. Now, put the swing set on wheels, and place it on the center line of a highway, and pull it down the road. As the swing set oscillates back and forth over the center line, it will trace a sine wave across the center line of the highway. Eventually, the swing set will slow to a stop, tracing out a damped sinewave on the highway. (At least until someone calls 911 and the highway guys call the folks with the white suits and white wrist bracelets.)

For those that have heard of an oscilloscope, this is exactly what an oscilloscope does, but is capable of displaying sinewaves (Or any wave shape for that matter) at far higher frequencies. I’ve got three of them that will operate up to 100,000,000 cycles, or 100 Mhz. Far more expensive scopes can operate up to the many Gigahertz range.

Now, I’ve momentarily placed an alkaline cell across the aluminum plate/coil of wire thing, and let go. If a switch could be found that could briefly connect the alkaline cell across the coil at 72,000,000 times per second, this thing could send radio signals and affect our radios as interference. Ain’t no mechanical switch in the world that can be switched at 72 Mhz. However, transistors can be configured to operate as SWITCHES. So, If you take the aluminum plate/coil thing, and feed back some signal from the coil to the INPUT of the transistor, and do it right, you can make it oscillate at 72 Mhz.

One big problem. The frequency would be 72 Mhz. If you bring your finger near it, just having your finger near it will cause the dang thing to drift in frequency. This thing will drift all the way from channel 11 on our transmitters to the 75 Mhz channels on the surface radios used for race cars. Very careful design can result in a much more stable signal, but it would still be “very wide band”, far - far wider than the early radios we used in the 1970’s and 1980’s.

So what’s to do? We are all aware of something called crystals in our radios. Next issue we will cover crystals, what they are, what they do, how they work, how they might be damaged (read as crash).

How the RC Radio Works Chapter X

For those who've tried electrics, I've developed an on board computerized thing that performs following:

1. Records total flying time for the entire season
2. Records total AmpHours for the entire season
3. Records AmpHours for the current flight
4. Records live Amperes pulled during the current flight

The Astroflight 40 Brushless motor uses about 1.4 Amp-Hours out of the GP3300 NiHyd cells during an acrobatic 6 minute flight.

The new YAK-54 with Hacker A30-12XL pulls about 0.9 AmpHours out of the A123 2.3 AmpHour Lithium NanoPhosphate cells during a 6 minute flight. These A123 cells are different. Their voltage is the same at the beginning AND the end of the flight. Interesting.

The continuing saga on how our radios work. We've talked about resonant electronic circuits, that consist of a capacitor and inductor. Think of a capacitor as two metal plates, and an inductor as a coil of wire.

Just how do these items store energy? A capacitor stores energy as a voltage across the metal plates. These items can range from extremely tiny, like those used in the new 2.4 Ghz radios to 0.2 Farad, 80 volt monsters used where I work, to 0.05 MicroFarad 34,000 volt capacitors used in the electric power field for correction of power factor. The 0.2 Farad capacitor is not really dangerous, unless you try to discharge one with a screwdriver. The resulting flash of very high current (1000 Amps) will vaporize the end of the screwdriver. The 34,000 volt units, well if you ever come across one, run like heck, since discharging one of them with your body could put the grass on the wrong side.

Now, an inductor stores energy as current, which in a coil creates a magnetic field. OK, a capacitor stores energy as a voltage, and discharging it creates current. An inductor stores energy as current in a coil of wire, and discharging it can create voltage, if you are not careful. In fact, this is exactly what happens in the ignition coil of the gasoline engines, even those used in our model airplanes. Now, if you charge a capacitor, connect it to an inductor, the energy will slosh back and forth as voltage on the capacitor, current on the inductor, swinging back and forth until all the energy is gone. As previously mentioned, this does not exactly create a very stable signal.

Enter the crystal. Just what is a crystal? It's literally a piece of quartz. Long ago, folks found out that if you apply a voltage to this stuff, it will warp, very slightly, but it will warp. If you hit it with a hammer, it can develop a voltage. You've seen this before on your igniters for your gas grill. Clobbering a properly shaped piece of quartz can develop several thousand volts. As for warping a crystal, you've heard them before, they can be used in the battery operated home fire alarms as the noise maker. This fire alarm noise maker is a version of an electronic oscillator built with a crystal, a rather large crystal.

Now, these crystals can be designed to vibrate over an extremely narrow frequency range. Now as this thing vibrates, it will put out a voltage, as it happens it will approximate a sinewave.

If this crystal is connected between that pair of aluminum plates and the coil of wire plus transistor mentioned previously, it can force the transistor to oscillate at a very specific frequency, namely that of the crystal. But, this will only work with a properly designed circuit. Also, the crystal must have a natural vibration identical to the resonant frequency of the aluminum plate/coil of wire thing. You can't take a crystal circuit that operates at 72,000,000 cycles per second, and connect it to a capacitor/inductor tuned to 108 Mhz. It won't work.

By the way, our transmitters have several tuned circuits, including the ANTENNA! These antennas are tuned to 72 Mhz when fully extended. When they are retracted, (such as range testing) the antenna is tuned to a higher frequency. This throws the whole thing out of kilter, resulting in a severe reduction of range. Makes it possible to range check our radios without walking ½ mile or so. Now, the crystal and its amplifiers are still tuned to 72 Mhz. This is like the old swing set that swings back and forth at exactly 1 cycle per second. If you push exactly one cycle per second, it will swing very nicely. But, if you shorten the chains on the swing by 2 feet, (or shorten the antenna) and still try to push exactly one cycle per second it becomes very difficult. You have to work a lot harder. Same thing happens in our radios with the antenna down, the transistors have to work harder with the antenna retracted.

Our radios are operating at 72 Mhz (72,000,000 cycles per second). These radios are known as narrow band, with a 5000 cycle band width, that's 5000 divided by 72,000,000 or about 0.007 percent, rather narrow indeed.

These crystals are actually vibrating in our radios millions of times per second. No, not 72,000,000 times per second, but often a lower frequency such as 72 Mhz divided by two or three. Then electronically, the frequency is multiplied up to 72 Mhz. Exactly how these frequencies are derived is different between brands of radios, and is one reason it is not a good idea to mix crystals between a Hitec, JR or other brands of radios. Some combinations of crystals and radios just don't work at all.

Now, something that can vibrate at millions of times per second has to be rather small. This can lead to problems when the crystal is mounted inside its case, the case you insert into the receivers. Dropping one of these things to a cement floor is not good for them, even worse is trying to fly an airplane two inches lower than the ground level.

Next we will cover modulation on our radios. (I've got a very old Citizenship radio where the modulation is your finger pushing a pushbutton!) Also, our transmitters are transmitting to anything near by, including the antennas of other nearby transmitters of your flying buddies. Don't get closer than 4 or 5 feet of a flying buddy. I've looked at the transmitted signal of a transmitter when another of a different channel is brought within 4 or 5 feet. These things really interact. Maybe not crash type interact, but they do interact.

How the RC Radio Works Chapter XI

Previously, we covered the transmitter signal, and how its controlled by a crystal. This crystal is electrically wired into several radio frequency amplifiers, and is directed into the antenna we all see on the top of our transmitters. The nature of a piece of wire, (Antenna) is it will radiate radio waves if a Alternating Voltage is connected to it. Now as previously mentioned, you are using audio frequencies, this piece of wire has to be miles in length to be effective. Moving up to our RC 72 Mhz frequencies, it can be on the order of several feet, and moving up to the Spektrum 2.4 Ghz frequencies, the antenna needs to be inches in length.

But, so far, all we have is a signal. This signal is known as a carrier frequency in the radio language. Not much can be done with just the signal. I have in my basement a very old Control Air transmitter/receiver that used a 9 volt carbon type battery. The transmitter and receiver are both turned on, and nothing happens. The transmitter has a push button on the panel that mixes an audio tone on the radio frequency carrier, causing a relay in the receiver to close its contacts. That it. No proportional controls no servos, no nothing. What this thing did was allow the modeler to operate a rubber band powered escapement that controlled only the models rudder. When the push button was pushed, the rudder would go from center to left. Pushing it again, the

rudder moved back to center, then to right, then center, left and so on. And if you pushed the button to many times, the rubber band unwound all the way, and you now had a free flight model. This radio is from the very early 1960's and was the best of the equipment of that era. Interesting enough, it cost about a hundred dollars in 1960 dollars, about what one months rent would have been.

Pushing the button on this transmitter caused the carrier frequency to be modulated by Amplitude Modulation, or AM, a term many of us may recognize from some of the RC systems we have owned. So, just what is AM? Or FM for that matter?

Back to the swing set. Remember getting out of jail after our episode of pulling the swing set with the leaky bucket down the highway? The swing set oscillating back and forth left and right of the highway center line is identical to the carrier wave described above, if we keep the swing set oscillating back and forth at an exact constant rate. But, if we cause the swing set to first swing back and forth while moving the swing set down the highway, then slow the swing set to a stop, still pulling the set down the highway, then swing it back and forth again, repeatedly, we will have a sine wave on the pavement from the previously mentioned leaky bucket filled with ink. Then we will have just a straight line when the swing set comes to a stop, then a sine wave, then a straight line, and on and on. This is exactly what is happening with the transmitted signals carrier wave. In fact, looking at the transmitted signal with a high frequency oscilloscope would look identical to the ink from the leaky bucket splattered on the pavement.

What we have done with this Amplitude Modulation, is superimposed a second, much much lower frequency on top of the modulated carrier frequency. That is Amplitude Modulation, where the AMPLITUDE of the 72 Mhz frequency is varied from normal, to zero, to normal, to zero, to normal to zero, you get the idea.

Amplitude modulation has served the radio industry very well over the past 100 years or so. It's still used in our AM radios, its used in parts of the television transmitted signals even to this day. Its main drawback is that during part of the time, NO SIGNAL is being transmitted. What this means is, if someone or something on the same frequency is transmitting from far away, it can interact with the receiver, and cause receipt of double signals, or worse, send the servo's all to one direction, resulting in the usual model airplane shaped impression in the ground after landing.

Next issue we will cover FM or Frequency Modulation.

How the RC Radio Works Chapter XII

More on batteries!

The magazines (and the Internet) have recently had a number of publications concerning the use of undersized receiver batteries on our larger models. The Spektrum Radio web page has published an article explaining several loss of models crashes due to this phenomenon. If you would like to see the original Spektrum article, it is available at their web page.

What is involved is the use of undersized receiver batteries with too many servos, notably the new digital servos. The proper way to determine if you really have a severe problem is to connect an oscilloscope to the receiver's 4.8 Volt battery connection, then cycle the heck out of the servos while watching the scope for any severe millisecond long voltage drops.

Since most of us do not have access to an oscilloscope,. Other verification means are available.

One of them is to purchase a short servo extension cable cut it in two, and strip all leads from both cables. Next, wrap the two black wires together, the two red wires together, the two signal wires together. Get some banana jacks from Radio Shack, and connect one banana jack to the pair of black wires, the second to the red wires. The signal wires should be soldered up and covered with shrink tubing. Now plug in the banana jacks to your digital volt meter, and the cable to an unused servo connection on the receiver. (IN THAT ORDER!. Otherwise, if the plug is inserted into the receiver and the banana jacks short together, you've shorted out your battery!) **Make certain your volt meter is on a voltage range, not a current range.**

Now, what you have is the ability to measure the voltage that is actually available at the receiver. Next, move several servo's to their extreme, and manually load them while returning the servos back to neutral. Load them just short of stalling the servos. Don't do this for more time than it takes to read the meter, the servos are pulling a lot of power while doing this.

If your volt meter drops much below 4.4 Volts DC, you need a bigger battery, bigger wire switch harness, or both. Best yet, is to go to a 5 cell battery pack with 2400 Ma Hr sub C NiCad's or NiHyd cells.

This same harness has other uses. If you are placing the servos at the rear of the fuselage, before installation of the servo, prepare the servo extension cables, and assemble the whole thing on your work bench. Connect the servo extension cable to the receiver, plug the other end into the voltmeter extension cable, then the servo into the other end of the voltmeter extension cable. You can now load this servo at the end of your extension cable and see just how much voltage you are loosing on your extension cable. If its more than a few tenths of a volt, you need heavier wire. Again, this is where is where the 5 cell battery pays off.

Just a last note, the August 2007 issue of RCR magazine has a Radio Ramblings article by Tony Stillman concerning use of a 5 cell battery pack with the **JR Sport ST125MG** servos. **Seems these servos do not work properly with 5 cells.** Gordon Banks publisher of RCR magazine indicated these JR servos jittered like crazy on 5 cells. Word to the wise, their may be other servos with similar problems.

How the RC Radio Works Chapter XIII

Last month, we discussed modulation of the radio signal that is transmitted from our RC transmitters. Without the ability to modulate the transmitted Radio Frequency Signal our RC radio's would not work. In fact, without modulation, we wouldn't have radio, TV, cell phones it would be a very different modern world.

By the way, last month we went back to the swing set, describing sending the swing set back and forth while pulling it down the highway. The leaky bucket full of ink will trace out a sine wave on the highway. Now, lets swing the swing set a little faster. OK, a lot faster, like 92,000,000 times a second. And, pull the swing set down the highway at 186,280 MILES per second. This would result in a wave shape very much like what some of us have heard as a wavelength of a radio signal. Since the speed of 186,280 miles per second is constant, varying swinging the swing set back and forth at different speeds will result in different wavelengths of ink spread on the highway. Some may recognize 186,280 miles per second as the speed of light. And, 92,000,000 cycles per second is the transmitted frequency of our RC radios.

For what it's worth, if you take a TV set, put on a set of rabbit ears, tune it to channel 4 or 5, and turn on an AM RC transmitter near by, you should be able to hear, and possibly see the signal on the TV.

We've covered AM (Amplitude Modulation) last issue, where we literally turn on and off the transmitted signal at a fairly high rate, usually in the audio frequency range.

FM modulation is a whole different animal. Note we've talked AM and FM. What is PCM and others?? Turns out they are just a variety of FM modulation. We'll talk about PCM in another issue.

FM modulation is an electrical frequency variation of the actual transmitted frequency at a regular rate. In fact, FM stands for Frequency Modulation. Fancy words. Just what the heck is it?

As discussed, AM modulation is varying the magnitude of the swing set, back and forth over the highway center line. Same as varying the volume control of your TV, and in fact, varying the "Volume" of the radio transmitted signal is done electronically, creating an Amplitude Modulated radio signal.

FM is FREQUENCY variation of the transmitted signal. With FM, the amplitude of the radio signal does not vary with modulation, only the frequency. Back to the swing set. Lets swing this swing set back and forth exactly 1.000000 cycles per second. Lets see, that's 60 cycles per minute, 3600 cycles per hour, and 86,400 cycles per day. You may have heard that we have a 5000 (5 Khz) bandwidth limitation on our radios, defined as narrow band years ago. OK, if we apply the ratio of 5000/72,000,000, we come up with 0.0000694. So we are varying something at about 0.00694 percent. Turns out, what we are varying is the FREQUENCY of the transmitted signal by some 0.00694 percent. Relating back to the swing set, if we consider 86,400 cycles per day as the carrier frequency, and change the cycles per day to 86406 cycles per day, this is how much we are modulating the signal. No, it is not much. Note we can either INCREASE the frequency, or we can DECREASE the frequency, radio wise, its same thing. But for our RC radio systems, it is one reason why some transmitters and receivers brands should not be interchanged.

Something very similar in nature is an guitar player, who strums the strings, then varies the pitch of the note by sliding the strings sideways on the guitar frets. Some of the guitars have a lever that is used to vary the pitch by just placing pressure on the lever. Same principle, but far higher in frequency in our RC transmitters.

Now, reflecting back to our actual transmitted frequency, we are transmitting at 92,000,000 plus 5000 (or minus 5000 depending on brand of radios). This accounts for the so called narrow band radios. The older radios varied the signal by four or five times this amount, the so called wide band radios that are no longer allowed at most flying fields.

Now, keep in mind, we are not transmitting music, or TV signals from our RC transmitters. In fact, transmitting music on an AM transmitter, you can literally see the music modulation on the radio frequency with a high frequency oscilloscope. Not so with FM. It takes special electronics to figure out what is going on. This decoding is accomplished inside the receiver.

So just what are we transmitting, if not music? Turns out, we are transmitting one's and zero's. Yep, the modulated signal is either "yes" or "no", just like my old Craftair radio with the push button on its front. It's the same thing, AM or FM, and PCM for that matter.

Next issue, we will discuss some of the ramifications of the narrow band radios, and how it limits just how much information can be transmitted during a measured period of time. And, just what is PCM and other coded signals?

How the RC Radio Works Chapter XIV

August, we discussed modulation on our radio control systems, indicating that we are transmitting "Ones" and "Zeros".

Just what are we transmitting?? The same type information is being transmitted, whether we have AM, FM or even PCM transmitters. What we are transmitting is a train of pulses, three pulses for a three channel

radio, four pulses for a four channel, 10 pulses for a 10 channel radio. For a three channel radio, we transmit three pulses, wait about 0.05 seconds, and transmit another three pulses, and on, and on, and on.

Take a look at photo #1. This is a photo of one of my Tektronix scopes. This is a Tek 2236 that can display from Direct Current (Battery) to over 100,000,000 cycles per second (100 Mhz) on its display. (If I crank up the sweep rate on the scope, it will show the radio signal as a sine wave.)

Digital photo #2 shows the radio frequency output of an old three channel AM radio. Note that the display has three pulses, followed by the “rest” period. Remember the swing set that swings left and right of the highway center line. Only here, the scope is swing above and below the “Center line”. Note that the signal is swinging back and forth about 100,000 times for each “Pulse”, resulting in a solid display. Each pulse corresponds to the Engine, Rudder, Elevator respectively on this old three channel radio. Note that on AM signals, the radio frequency is actually OFF part of the time. This is the big drawback of AM radios. If any other radio should hit this signal, and fill in the “zeros”, you have a condition where all the servos on the model lock over, and you crash.

Note the last pulse on photo #2. Compare this last pulse to the same pulse on photo #3. If you compare these pulse widths to the screen lines, you will find that the pulses vary from 0.001 to 0.002 seconds in width. This translates directly to the position of the servo. 0.001 second or one millisecond corresponds to “Full left”, 0.002 seconds corresponds to “Full Right”. Each of the three pulses can be varied by the transmitter’s various sticks. Note the solid signal to the far right of the screen. This is the “rest period” and is used to synchronize the receiver for each “Frame” of transmitted signal.

So, the WIDTH of the pulse for each stick position directly corresponds to the POSITION of the associated servo.

Now, for FM, everything operates the same, only instead of the signal going to zero, it changes FREQUENCY, very slightly. It’s the job of the FM receiver to decode it.

Photo #1

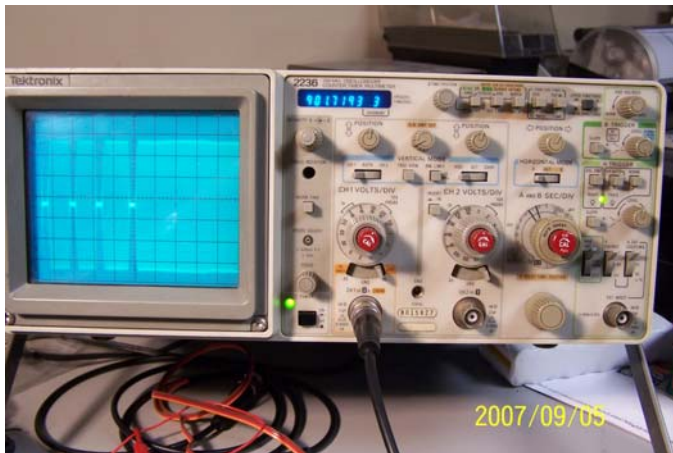


Photo #2

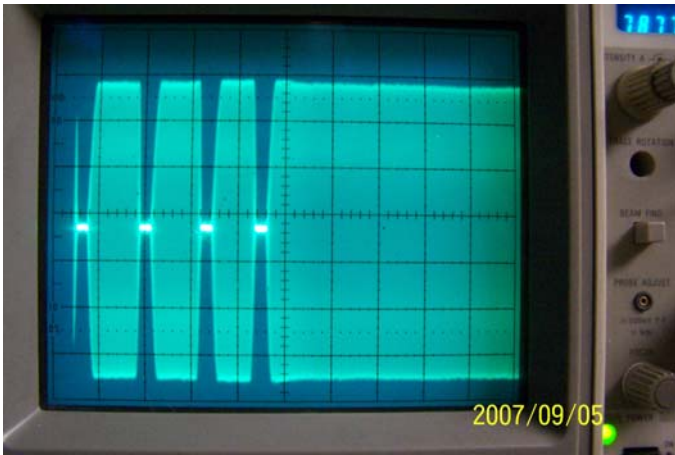
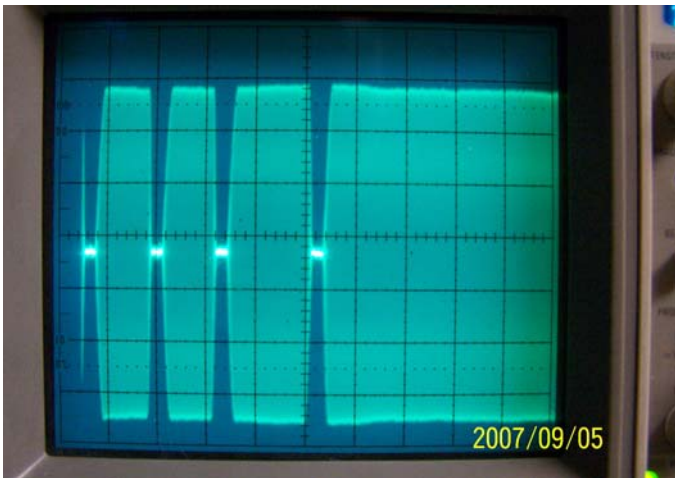


Photo #3



So, just what is PCM and other similar products?

PCM stands for Pulse Coded Modulation. (That's nice, so just what is Pulse Coded Modulation and other similar products???)

Up to this point, we've been looking at signals from the transmitter that correspond DIRECTLY to the signals that are applied to the third wire of the servos. We are getting ahead of ourselves, but the receiver splits up the pulse trains from the transmitter, and applies one pulse only to each corresponding servo.

PCM is a different animal. Instead of transmitting pulses over the radio signal, the transmitter essentially transmits digital NUMBERS. This is where the 1024 and 2048 designations comes from. The transmitter transmits numerical numbers from zero to 1024 for the rudder, 0-1024 for the elevator, 0-1024 for the throttle, and so on. The 1024 comes from $2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2$. Yep, this is binary code. We've also got 2048 radios, but I don't know if any servo's are capable of holding this type of resolution.

So what's the advantage?? We can put a little microprocessor into the receiver and have it look at these numbers. It's the nature of microprocessors that they really work well handling numbers. And they are excellent in determining if the numbers received from the transmitter are indeed correct, and not wrong in some way such as getting hit by some noise or near frequency transmitter.

These little microprocessors (actually microcontrollers) can also be easily be programmed to look at the incoming number stream, and if it looks really bad, the microprocessor can run the models servos to some preset position, such as low engine throttle and the like. For general information, any microcontroller can easily do a million calculations per second. You can buy them for a few dollars. One of these was used in my "RCHOURMETER" project in the RC Report magazine a few months ago.

Now, just what is SPEKTRUM?

Well, JR is pretty secretive on what they are doing. They have indicated verbally that interference is pretty much impossible, even if someone should ever wind up on the same frequencies being used on the Spektrum radios.

How can this be? This is speculation on my part. What we do know, is the Spektrum DX7 series is transmitting at 2.4 Ghz, with what they are calling wide band signal, that apparently is one megahertz wide. The Spektrum transmitter alternates between two different channels in the 2.4 Ghz band.

One problem with modulation of a radio signal, is the modulation itself causes the bandwidth (5000 cycles per second in FM) to become wider. This kind of limits just how much information you can send by FM.

This is not a problem with the 2.4 Ghz radios. You can transmit a phenomenal amount of information with a 1,000,000 cycle per second bandwidth.

Before the transmitter/receiver will work together, they must be bound" together. I'm not certain what they are doing, but suspect they are doing something similar to what is used in the Internet, and also used where I work.

What these internet folks are doing is sending out "Packets" of information at a very rapid rate. (A packet of information consists of a quantity of information. It can be compared to a book, where one packet is one page out of the book.) For our RC radios, each packet of information would contain a portion of the required signals for the rudder, elevator, throttle and so on.

I suspect, similar to the Internet and where I work, each packet of information also contains a digital code that is unique to the transmitter, and its selected model type. Since every 2.4 Ghz transmitter manufactured throughout the world has a different unique number, you can't screw it up.

The receiver's microcontroller looks for this unique number from its "bound" transmitter. If one packet has the wrong unique number, the receiver simply ignores it, and takes the next packet to come along. Also being transmitted with these packets are "error codes" where if the packet is contaminated, the error codes can be used to either ignore the packet, or use it after correcting any errors that exist.

This suggests that the receivers microcontroller is very busy in examining all of this stuff, splitting it up, and feeding it to the various servos as required.

Some of the club members may have seen my E3D 48 inch, 3.5 pound model from last year that has been retro-fitted with a Hacker A40-10S motor, running a 13 by 6.5 prop at 7700 RPM, with four A123 cells. It's the first model I've had that will fly straight up and keep on going.

One of our club members is considering putting electric in a sea plane. The Hacker A40-10L motor, running on six 3700 Amp Hr Lipo's will turn a 12/6 (or 11/8) prop at 11,500 RPM. This represents 1.25 Horsepower on a battery- motor system that weighs in at about 33 ounces. That A40-10L motor is rated at 45 amperes continuous, and some 60 Amps for 15 seconds.

How the RC Radio Works Chapter XV

Now, for those who would like to purchase a new radio for the next flying season, what should we buy?

This is my personal opinion, take it for what its worth.

We have the following considerations.

1. The original 72 Mhz radios
2. The Spektrum 2.4 Ghz radios
3. The Futaba 2.4 Ghz radios

What are the features of these units? Well, the original 72 Mhz radios have been around for decades, and have worked very well on virtually every type of model airplane flown. They do have the potential to be “Shot down”, but under proper frequency control procedures, this is not really a big issue. They do have very reasonable prices as compared to the 2.4 Ghz Microwave radios. The bottom line, if you are using 72 Mhz radios, if they have been working fine, there is no need to upgrade to the microwave units.

However, if you want to go to the newer systems, these microwave radios have a lot going for them, including not being shot down by another modeler, you can turn on without concern if anyone else is on your frequency. They are pretty much immune to electronic noise like ignition engines, and so on.

We have the Spektrum radios built by JR that selects two unused frequencies in the 2.4 Ghz microwave frequency bands. We have the Futaba 2.4 Ghz radios that use the “Frequency Hopping” process in the 2.4 Ghz frequency bands. Which is better?

Well, Spektrum indicates that they tried the “frequency hopping” process during their early designing process, decided that this type radio had a few disadvantages. They indicate that the system they are using is more complex than the frequency hopping process. The Spektrum radios use a dual receiver system for the models that require range of more than a few thousand feet. These receivers can handle anything from the one pound models up to the full blown jets that move around at speeds of near 200 mph. Spektrum has single receivers for the “Foamies” that weigh less than one pound with a stated range of several thousand feet.

Spektrum has the “Model Match” system where it is not possible to program in the wrong model into your transmitter and take off with the wrong airplane. For those who regularly show up with several different models, this is an important issue. I’ve not found this feature in the Futaba Radios.

Spektrum now has 9 channel radios for those requiring more channels for the larger models.

Futaba uses the “frequency hopping” process. Futaba indicates this is patterned after their years of using the frequency hopping process in industrial controls. Some of the Internet sites have indicated that if a number of Futaba transmitters are on at the same time, that “Collision” between transmitters will occur. This has the capability of slowing down the rate of transmitted servo commands. I’m not certain this is true, due to the previously mentioned ability of microwave radios to transmit a phenomenal amount of information over a short period of time. So, even if the Futaba radio system should get “Hit” 50% of the time by other Futaba radios during frequency hopping (I’m NOT saying this is the case!) the remaining 50% of good signal is still far more than is required to control your model.

So, which is better? For those that have used the JR radios for years with success, the Spektrum microwave radio is better. For those who have used the Futaba radios for years with success, the Futaba microwave radio is better. For those with HiTech radios, (Flip a coin!).

(Update, Spektrum now has a new receiver specially designed for the larger models. Check the magazines, it’s the receiver that has two separate #16 wires for the dual battery setup.)

Next issue, we start on receivers, single conversion, double conversion and what they are, and how they work.

How the RC Radio Works Chapter XVI

Back in the 1960's the now defunct RCM magazine ran an article where one modeler checked vibration levels in a typical 60 powered model. The vibrations levels found could exceed 35 **G's!** NASA gets very nervous about vibration levels that exceed 8 or 10 G's.

But, one big side effect of the modern radio receivers, is they are far lighter than receivers of 10 years or so ago. So what??? It involves how we mount these things in our models.

I wrote an article in the 1960's in the RCM magazine about vibration, and how to keep it out of your radio. Back in those days, radio receivers used individual components such as resistors, capacitors, transformers and so on. Repeated vibration could and did lead to fatigue of the component lead wires, resulting in them breaking off. And the model usually crashed. Yeah, I lost several models due to this phenomenon. My article suggested putting the whole entire radio system, including receiver, battery, switch, and servos into an isolated box, and connecting this box and its internal servos to the model surfaces with nyrods. The box was supported inside the model with soft foam. It worked, and worked very well.

Now days, we've got surface mounted components that reduces the effects of this vibration stuff. **BUT**, with the receivers that weigh in at fractions of an ounce, stuffing them inside foam for isolation is not as effective as putting a two ounce receiver inside the same exact foam for isolation.

Also note that other required items for the radio include the Nicad batteries, battery wiring, servo wiring, switch harness, the list goes on. Each and every one of these items are susceptible to vibration. Taking a typical receiver, Velcro mounting it to the fuselage, and plugging in the various cables to the receiver is asking for problems.

What can happen? If the receiver is mounted directly to the fuselage, it is subjected to severe vibration. As indicated, most surface mounted design receivers are resistant to this type vibration. However, the various plugs that plug into the receiver are not. Severe vibration can lead to servo leads "unplugging" themselves from the receiver, it could even result in fracturing the servo wires internally inside the servo wire insulation.

For those who build up battery or servo leads, be absolutely certain to use wire designed for this purpose. Radio Shack wire is OUT! The reason is, the model industry uses copper wire with very fine individual strands, and a lot of them. For those who have taken 3/4 inch diameter copper tubing from the hardware store and bent it back and for several times, you quickly find out it work hardens. (Smaller tubing can be bent more.)

The same can occur in our model wires, but the very small diameter strands in the "Good wire" reduce the damage potential that can be caused by vibration.

What you do NOT want is any plug or connection where one item is subjected to vibration, the other is not. Case in point, mount the receiver to the fuselage with Velcro, and just plug in the servo wires. The receiver will vibrate with the fuselage, the servo wires will flop around with each and every stroke of the engine. Maybe only a few thousandths of an inch or so, but over hours of flying time, these little vibrations can creep up on you.

The receiver on-off switch is another hot issue. These switches are usually mounted directly to the fuselage and are subjected to a lot of vibration. Not much can be done about this. Some vendors are selling electronic switches, where the on off switch operates high power transistors that power the receiver and servos. These high power transistors (Field Effect Transistors) will have a lower voltage drop than the switch contacts they replace. Its easy to find a FET that will handle 50 Amps, they use them in virtually every Electronic Speed Control for electric models made.

FYI, you can now go out and buy a diode rated for about 1000 Volts DC and 10,000 Amperes. That 10,000 Amps is not a misprint. That's some 13,000 horsepower.

How the RC Radio Works Chapter XVII

As we have previously discussed, our transmitters send out a 72 Mhz radio frequency to everything within range. Problem is, we also have the television bands, AM and FM bands, CB bands, Industrial bands, Amateur Radio Bands, Paging bands, the list goes on and on. Some of us may know that our RC channels are placed in between the commercial paging frequencies. These commercial paging systems are allowed far higher transmitting power levels than are allowed in the RC channels.

So, just how does the RC receiver select only the proper frequency and no others (hopefully!)? The answer is resonance, something that was mentioned in the beginning of this series of articles.

As previously mentioned in this series, many of the mathematical formulas and principles of operation are identical between the electrical and mechanical world. Resonance is one of them.

Take hearing as an example. If you are talking with another person, you can recognize his response and understand what he is saying, even several other people are all talking at the same time. It's the human brain that separates much of the clutter from other people making it possible to understand what the person you are talking to is saying.

How ever, it's a much different situation where you are trying to talk to some one in a crowded meeting room of 100 or so people. It just becomes noise.

Many of us have been in our home, watching TV when a truck with a loud muffler rumbles by, causing the picture window to rattle. Note that if the truck speeds up, or slows down, the window won't rattle.

The window will still rattle from the truck even if those 100 people are in your living room all at the same time (assuming your floor collapsing doesn't cause rattling of its own).

It turns out that the truck is transmitting a specific frequency proportional to how fast the engine is turning over. The window also has a resonant frequency, that if it is the same as the truck engine, it will begin to vibrate.

Almost any mechanical object that has rigidity will have a resonant frequency, from the wind chimes we have outside, to the bridge that we've all seen on TV that collapsed some 80 years ago when wind caused it to oscillate at its resonant frequency.

Remember the electronic resonant circuit first shown in the beginning of this series, consisting of a pair of aluminum plates and a coil? Same thing applies, exactly.

How the RC Radio Works Chapter XIII

Last issue we suggested that the receivers work with resonance. This is very true, and the photo of the two pieces of aluminum separated by a piece of paper, and connected to a coil of wire showed earlier in this series is exactly what is used in the first part of the modern day receiver. However, we've all observed a piece of wire that is about 30 inches long coming out of our receivers. The question is, just how is this piece of wire connected to the aluminum/coil contraption?

Well, in real life, the aluminum/coil thing is shrunk down by several magnitudes in size so it will fit inside the receiver. The capacitor will be of a type that is quite small, very accurate in its value, and very stable in its value over temperature ranges and so on. The coil will also be quite small, and will have more turns in its winding. It will also be wound inside a ferrite core that allows shielding, and adjustments for tuning. FYI, a ferrite core is a special type of powdered iron transformer thing that completely encloses the wire coil. This ferrite core usually has a moveable ferrite iron core that is used to tune the whole capacitor/core thing. Depending on the manufacturer of the radio, you will likely find that this core has been factory adjusted, and sealed with wax to prevent vibration from affecting its tuning.

Now, we must connect the receiver antenna to this ferrite transformer device. This is normally done by taking the coil winding, and tapping it in the middle. The receiver antenna is then connected to this “tap in the middle” of the winding. So far, this whole capacitor, ferrite core and winding is tuned to the 72 Mhz frequency of the receiver.

NOTE THAT THE ANTENNA IS ALSO PART OF THE TUNED CIRCUIT. CHANGING THE LENGTH OF THE ANTENNA IS THE SAME AS SHORTENING THE ANTENNA ON YOUR TRANSMITTER!

I've seen several cases where the receiver was installed inside the model with the antenna nicely coiled up just as it was shipped from the factory. One was a very nice fully detailed four motor electric scale model that flew for about 500 feet before it went in. (The modeler was a very well known person that has authored more than a few articles in the AMA magazine.) Just to show it can happen to anyone. Just a simple range check would have prevented this crash.

Now, just what kind of signal levels are involved with this setup? Well, this signal level can vary by many orders of magnitude, depending on how close or far away the transmitter is. When the transmitter is very close, on the order of a few feet, this signal level will be on the order of a volt or so as measured on the antenna. And, if the transmitter is about ½ mile or more away, this same signal will drop down to one or two Microvolts. Microvolts?? A microvolt is one millionth of a volt. Now, this is a resonant circuit, and one of the properties of a resonant circuit is that due to the energy slopping back and forth between the capacitor and coil, the voltage can actually increase above the level found at the antenna. Think about the swing set, and nudging the 500 pound block of cement back and forth with a push of your finger. A good tuned circuit can actually increase the voltage of the very low level signals by 50 or 100 times. However, this is still very low when the model is far away, so we need to boost the signal a little.

So, we attach a transistor (Or FET, Field Effect Transistor) to this capacitor/coil thing to boost its voltage. This whole combination of the capacitor, ferrite core/coil is referred to as the Radio Frequency or RF circuit of the receiver. Now, by itself, this RF circuit will not be enough to make this thing work. The major problem is it will receive TV channel 4, paging frequencies, all the RC channels, including the 72 Airplane frequencies and the 75 Mhz ground frequencies.

We can add several more of these “RF circuits” to narrow the bandwidth of the setup, but this just won't do the job, no matter how many RF amplifiers we add.

What's to do? Next issue, we start on the superhetrodyne radio, and just what single and double conversion is.

How the RC Radio Works Chapter XIV ON BOARD 2.4 Ghz VIDEO TRANSMITTERS ON FUTABA/SPEKTRUM 2.4 GHZ RADIOS

Long ago, I was a member of a local model sail plane club. One of the problems we had was when the club members were spread out across the flying field, flying the sail planes. This worked very well, unless you flew your model 1000 feet away, over the head of another member also flying a model. The poor receiver tried to deal with two different channels, with a very substantial difference in signal level. Often times, when the model passed over the distant transmitter, the receiver couldn't handle the difference in signal level between the near by and far away transmitters. The result is a severe glitch that could result in a crash of the model flying over the distant transmitter. This is not an issue with our club, since all pilots must be located in the pit area.

However, various internet locations HAVE indicated this CAN be a problem with the new microwave radios. How??, When we have all transmitters located in the pit area, it is NOT a problem. The problems start when the pilot installs a video camera with a radio link back to the ground. This video transmitter is likely to be on the same radio band that the microwave Spektrum/Futaba radios are on. This results in a very strong radio transmitter located only a foot or two from the model radio, providing a volt or so of radio

signal on the model radios RF section. Superimposed on this volt or so of radio signal from the video camera is a signal a million times lower from your transmitter located on the ground.

It would take a receiver with an exceptional Radio Frequency amplifier design to not be affected by this gigantic difference in signal level between the two different transmitted frequencies.

If you are planning to do this onboard video camera with a radio link to the ground with a Spektrum/Futaba microwave radio, make absolutely certain you do not have a range problem before flying anything. Check range both with the “reduced power” switch AND with full range for at least 1000 feet.

Oh, just a note on these 2.4 Ghz microwave radios. The December 2007 issue of RCR magazine has a test on an ignition engine. The article indicates that the ignition engine had so much radio interference that it was not useable with the 72 Mhz radios. They tried this same engine on the 2.4 Ghz microwave radio. Guess what? No interference what so ever.

Interesting Internet site, run a google search for the “worlds largest diesel engine”. This is a monster of an engine that has a 300 ton CRANKSHAFT! It’s the size of a pretty large house. This thing burns about ½ gallon of fuel for every revolution of its crankshaft.

Another interesting Internet web page is www.rcraze.com. This site has a lot of videos on model airplanes, many of which are electric.

How the RC Radio Works Chapter XV

Last issue, we talked about the radio receiver Radio Frequency RF section. This is a comparatively wide band circuit that can cover the entire model 72 Mhz region without retuning between channels 11 and 60. A radio frequency circuit just simply can not pick out channel 16 from 17, or channel 11 from 60 for that matter. It’s a matter of ratios. Channel 11 is about 245,000 cycles per second (245 Khz) from channel 60, this is a ratio of 245,000 divided by 72,000,000 or about 0.35 percent of the 72 Mhz frequency we are trying to tune. As previously mentioned, we need to narrow this down to 5000 cycles per second, or 5000 divided by 72,000,000. That’s about 0.006% of the 72 Mhz frequency. We need to improve the selective function of the radio by some 50 times. Well, we can not do it by the radio frequency circuit alone, it just won’t work. So now what??

Well, very early in the radio design era, some 80-90 years ago, someone got the idea of mixing the radio frequency we are trying to receive with another frequency, and the superheterodyne or superhet was born. As you can see, this is not a recent design, its been around for near a century. So just what are we doing?

Many of us have watched someone taking a model airplane twin engine and adjusted both engines to be synchronized. Its hard to describe, but very obvious when both engines are at the same exact frequency. But, when the engines are not at the same exact frequency, you get a “beat frequency” that again is hard to describe, but very obvious when you hear it. So, what you have if one engine is running at 12,000 RPM, and the other at 13,200 RPM, is two engines that are running at 200 cycles per second, and the second is running at 220 cycles per second (just divide RPM by 60 to get revolutions per second). What you hear is the first engine at 200 cycles per second, the second at 220 cycles per second, and out of the blue, a third frequency of the difference of 220 minus 200 or 20 cycles per second. That 20 cycles per second is what you are trying to tune out by adjusting one engine faster or slower to match the other engine. Oh yeah, there is one more frequency generated of 200 plus 220 cycles per second (or 420 cycles per second) buried in the noise that does exist in this entire mess.

On a similar note, many of us have watched someone tune up a guitar by matching one string’s frequency against another, and twisting the string tension knobs to match up. Same thing exactly.

And, again, this stuff translates exactly to our electronic stuff. Lets take one of my old radios on channel 37. It is marked as transmitting at 72,530,000 cycles per second or 72,530,000 Hertz. We can simplify this to 72.53 Mhz, but will use the full number for the time being.

Now, if we electronically mix the 72,530,000 with a local 72,057,000 local frequency, we get 455,000 Hertz out. As it turns out, if the “Mixing frequency” is a very pure sine wave, the information or modulation present on the original 72 Mhz frequency will also be present and will be identical on the 0.455 Mhz frequency.

With this much lower 0.455 Mhz frequency, we can design a very narrow band circuit that can pick out the required 5000 cycle bandwidth we need for our narrow band radios. (Some readers may recognize this 0.455 Mhz as 455 Kilohertz or the Intermediate Frequency amplifier also known as the IF amplifier. This is the basis of the single conversion receiver that works well in many receiver designs such as the AM section of our common AM-FM radios we have in our house. Next issue we will discuss some of the shortcomings of the single conversion radios as used in our RC systems. And why most 72 Mhz RC systems use “double conversion” on the receiver.

How the RC Radio Works Chapter XVI

I’ve worked for many years in the Service department of a company that manufactures very large circuit breakers used in the utility power equipment. These breakers have ratings of 38,000 volts and 600 Amperes full load, and can clear some 16,000 amperes in a short circuit. These breakers are commanded by electronic controls, the part I worked on for many years. We progressed from controls using vacuum tubes (Yeah I repaired them early on) to discrete transistors, to microprocessors, to very high performance controls that we use today.

Over the 44 years I worked at this company, we had repeated failures of the same time many times on all versions of the circuit breaker controls. We would conduct full factory testing, pack the controls and breakers into cardboard boxes, crate the circuit breakers in wood crates.

Then when the customer received the equipment, they would find electronic parts laying on the bottom of the control. They would have absolutely no damage to the shipping cartons or shipping crates. We’ve actually had all the 1/2 inch bolts come loose on 3 inch galvanized steel angle iron, dropping the circuit breaker from its mounting steel structure. All of these bolts had lock washers, and were installed with an impact wrench.

It did not take long to figure out what was happening. Seems the shipping damage resulted when the equipment was shipped on a nearly empty tractor trailer with a severely out of balance tire. The resulting pounding after a 2000 mile trip resulted in some controls breaking off a dozen or more electronic parts from vibration induced fatigue of the various components. We’ve gone to securing all “standing up electronic parts” with a special electronic compatible RTV compound on our equipment for the past 20 years because of this phenomenon.

So how does this affect our models??

We’ve talked above about mixing a new frequency with the existing transmitted frequency in the receiver. As you may suspect, this new frequency must be extremely stable or the darn thing won’t work. As it turns out, this new frequency is generated by a crystal controlled circuit much like that used in our transmitters. This crystal controlled frequency is controlled by the crystal we plug into our receivers. And, as discussed earlier, this crystal is actually vibrating millions of times per second as it generates our required frequency. Now, we have all taken a piece of metal, like those wind chimes some of us hate, and held them while whacking them with another item. If the chime is held at the exact center very loosely, it will chime very nicely. Take the same time, hold the chime with both hands, separated by several inches, and whack it again, it will not chime very long, if at all.

Same thing applies to the quartz crystal inside our two pin crystals we insert into our receivers. This very small quartz crystal is mounted very lightly inside the crystal case. Last summer, I really cringed when I saw a receiver installed into a gas powered model airplane with **VELCRO!** If that tiny quartz crystal inside the crystal case gets vibrated off its mounting clips, you crash. Period. A lot of other parts inside these receivers are subject to vibration, any one of which if suffers fatigue damage, you crash.

Last issue we talked about “mixing radio frequencies” similar to what happens when you hear two model engines on a twin airplane being synchronized. This process results in a “beat frequency” that is hard to describe, but obvious to anyone that has listened to it.

The same exact thing happens in our receivers, as well as our AM-FM radios, Televisions, Cell Phones, just about anything involving radio frequency. Now, for how it involves our RC receivers. (This is going to get pretty messy!)

We left off last issue with the IF frequency of 0.455 Mhz, or 455 Kilohertz. Lets use a typical radio for the following “How it works”. We can select channel 12, which transmits on 72.03 Mhz, or 72,030,000 Hertz (cycles per second.) We require a “Mixing Frequency” of 72,030,000 PLUS 455,000 Hertz or 72,030,000 MINUS 455,000 Hertz for the local oscillator. Different receivers use either the “plus” or “minus” for the other mixing frequency, which is why you should never mix crystals between radio brands. So, lets select the higher frequency which will be 72,030,000 PLUS 455,000, or 72,485,000 Hertz. The mixing process generates frequencies of 72,030,000, 72,485,000, 144,515,000 and 455,000 Hertz. This whole thing then gets sent to the Intermediate Amplifier, also known as the IF amplifier. The IF amplifier responds only to 455,000 Hertz, and rejects the other three frequencies. All works very good. But, there is a very big fly in the ointment!

Now, lets suppose some paging frequency (or what ever??) is transmitting near by on 72,940,000 Hertz. Lets see, we mix this with the receivers local oscillator of 72,485,000 and we get outputs of 72,940,000, 72,485,000 Hertz, 145,425,000 Hertz. But the last frequency is 72,940,000 Hertz minus 72,485,000 Hertz. That’s 455,000 Hertz!!!

That’s the &*#@%#\$ IF frequency! We just found out that our receiver responds to two different frequencies, 72,030,000 Hertz, AND 72,940,000 Hertz. The only thing in the receiver that can separate the two frequencies is the Radio Frequency (RF) Amplifier, and that RF Amp is not narrow band enough to do it. This in a nutshell is what is called the Image Frequency, and our receivers must have excellent Image Frequency rejection to work in the real world.

This article just described what is known as a single conversion receiver. We will cover the double conversion receiver in the next article.

How the RC Radio Works Chapter XVII

More than a few club members are flying expensive models involving quarter scale machines and so on. I just looked over what Spektrum RC has come up with for these models. They have released their new receiver, identified as model AR 9100. This is a Microwave receiver that operates 9 channels. The interesting part is, it has built into the receiver DUAL battery inputs, using number 16 battery wire, rather than the much smaller #22 or #24 wire commonly found on the general model receivers.

This receiver has three “slave receivers” included in the price tag. These slave receivers all plug into the main receiver for very robust signal reception. The design uses an on-off switch that, if it should fail, fails in the ON mode. Its apparently an electronic on-off switch. This receiver is directly compatible with all JR and Spektrum Microwave 2.4 Gigahertz transmitters. This thing is not cheap, the receiver alone is some \$220.00. But for the very expensive models, it just might be worth it.

Last issue, we left off with a description of the single conversion Superhet Receiver. This type of design uses one conversion directly from the 72 Mhz frequency transmitted to a 0.455 Mhz (455 Kilohertz) frequency where much of the amplification takes place. We showed that this type of receiver is subject to “Image Frequencies”.

Now, what if we converted the 72 Mhz frequency TWICE??. Let see, first lets convert the 72 Mhz frequency to a much higher frequency than 0.455 Mhz, say 10.7 Mhz. It so happens that 10.7 Mhz is a very common frequency that is used throughout the radio industry, both in RC radio systems, ham radios, AM-FM radios and a lot of other stuff.

50 Mhz, significantly lower than the 72 Mhz frequency from our transmitters. This difference is much easier to reject by the receivers Radio Frequency amplifier. This 10.7 Mhz first intermediate frequency is again down-converted to 0.455 Mhz by a second intermediate frequency conversion. The second intermediate frequency is where the majority of the “fine tuning” for our 5000 Hertz frequency bandwidth takes place.

Now, we have three crystals in our receiver. The first tunes in the 72 MHz frequency, the second tunes in the 10.7 Mhz frequency, the third tunes in the 0.455 Mhz frequency. Then again, many receiver designs may use ceramic filters in place of the radio frequency transformers that were used years ago. As previously mentioned, these crystals are more subject to vibration than most other parts in the receiver. It is a major reason that a receiver should **NEVER** be directly mounted to the fuselage by Velcro or similar in any model powered by a reciprocating engine.

Next, we will cover the remaining circuits in our receiver, such as the ring counter, automatic gain controls and so on.

How the RC Radio Works Chapter XVIII

So Far on this series, we have been pretty much dealing with radio frequency signals. This signal has been tracked through the transmitter and its transmitted radio frequency signals, the receiver and its antenna that receives the radio frequency signals. And the progression of these signals through the receiver as they are converted to lower and lower radio frequencies, in an effort to create a very narrow band that is required for our radios in today's environment. Now, for the first time, we will be dealing with what really amounts to audio frequencies, that is, if we tied a headphone to the signals we would be able to listen to them.

Way back in the beginning of this series we indicated that the transmitter is sending out a series of pulse signals, one pulse for each channel being transmitted. These pulse trains are being sent about 50 times per second. This pulse train is received in the receiver as a series of pulses, again repeated about 50 times per second. In the earlier days of our equipment, these pulses were separated by what is called a “ring counter” or similar circuitry. I won't go into how they work, since they have likely been replaced by a little microcontroller that performs this function along with many other functions. The bottom line is, this circuit pulls the first pulse out of the pulse train, and sends it to servo #1, it then pulls the second pulse, sends to servo #2, third pulse, third servo, you get the idea. Then after all pulses have been received, the receiver goes on vacation for about 50 milliseconds, waiting for the next string of pulses.

Now, this pulse is standardized on all RC radio signals, where a pulse of 1.5 milliseconds (0.0015 seconds) will drive the servo to its center position. A pulse of 1.0 milliseconds will drive the servo full “left rudder” and a pulse of 2.0 milliseconds will drive the servo full “right rudder.

One more thing on the receiver. This receiver must be able to work with both very powerful signals when you hold the transmitter over the model, and very weak signals when you are at the maximum range of the RC system. This will be about a mile or so with the transmitter on the ground and the model in the air. The signal variation is at least a million to one from close to far away.

The result is severe overdriving the receiver circuits when you hold the transmitter over the receiver. This is handled by what is called the Automatic Gain Control circuit of the receiver. The terminology is AGC

control. Several other terms are also in use such as Automatic Volume Control and similar. The AGC control circuitry reduces the electronic gain of the various radio circuits such that the output signal to the ring counter doesn't vary when the transmitter is moved from near by to a mile or so away. Some radio systems have been bragging about their AGC controls in their receivers. This is nothing new, these schemes have been around for 80-90 years and are part of every AM-FM radio, TV, CB radios, cell phones, you name it..

How the RC Radio Works Chapter XIX

One thing our RC systems all have is the servo that activates the various control surfaces of our models. This applies to model airplanes, model cars, and a lot of other equipment. The average full scale commercial jet plane is full of them.

So, just what is a servo? A servo is a device that has a signal input that controls an output shaft of some sort. You could even consider power steering in your car as a servo controlled by your steering wheel.

The servos we use are motor controlled with an internal gear box, and output shaft that we are all familiar with. Our servos have two power leads, the red (+) and black (-) wires, along with a third wire that contains the signal input from the receiver. As previously mentioned, this a repeating pulse signal is 0.001 to 0.002 seconds in length that repeats about 50 times a second. The exact width of this pulse determines the servo's output shaft position. Note that a time of 0.0015 seconds represents the center position of the servo. Now, if you could wire up a toggle switch to the red and black wires, and switch the signal input to the servo by properly flipping the switch, you would be able to control the servo. Problem is, you've got to flip this switch about 50 times per second with exactly 0.0015 seconds "on time" to have the servo move to its center position. That's where electronics does its stuff.

So exactly what inside this servo is controlling the servo output shaft? Well, way back in the beginning of this series, we mentioned a device called a capacitor. This gadget stores energy in the form of voltage, and it can be charged by many things, including a battery and a resistor. You connect a 5 volt battery in series with a resistor across a capacitor, and depending on component values, you can create a time delay that can vary from millionths of a second to minutes or more. With proper selection of parts, you can create a time delay of 0.0015 seconds. (Now where did that come from??) If you make that resistor variable with a potentiometer (Another name is volume control on your TV) and drive the position of that variable resistor with a mechanical connection to the servo's output shaft, we can use electronics to make it work. So, the servo gets an input from the receiver of say 0.0018 seconds (1.8 milliseconds) and the servos internal time delay with its internal capacitor, and resistor driven by the output shaft might be at 1.1 milliseconds. The servo electronics recognizes that the servo does not match the input signal, so the electronics drives the motor in the proper direction such that the servo's internal timer matches the input signal from the receiver. This is a description of what they call an analog servo, something we've had for RC models for 40 years.

Now, we've got what they call digital servos. What is the difference? Well, we still need the motor, gear box, potentiometer, and so on. But, we've replaced the internal time delay capacitor and associated parts with a computer chip. What's the advantage? Well, one of the problems with the analog electronics is a design issue where you need to have the servo respond with very close accuracy. But if you make the servo "to tight", the dang thing can hunt back and forth while trying to zero in on the exact position required, which is hard on the receiver battery and electronics.

The digital electronics makes it possible to program in exactly how this servo responds to the commands sent by the receiver. And, digital electronics will always respond exactly the same way, where component value tolerances have little or no effect on how stable the whole entire servo package is.

What can go wrong with these things? Well, early on, back in the 1960's, they used all "stand up" parts that were very susceptible to vibration. Nowadays, they all use surface mount parts that are pretty much

immune to this sort of thing. Even with glow/gas powered models, servo failures are rather unusual. Early on, the servo potentiometer used radio grade materials. We've all had radios that developed noisy volume controls. Long ago, these pots have gone to a ceramic based resistance element, a material that is very hard and difficult to damage.

So, this concludes the How It Works RC system series of articles. Hopefully it has provided some insight on how these devices work, and how to avoid problems with them due to vibration, battery problems and the like.

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