DSS R/C pioneer Dave Jones flying a model using his Infinity radio during a recent visit to Dalby Queensland. Dave was in Australia to watch the 2008 UAV Outback Challenge.

There is a revolution sweeping across the R/C model scene which will bring great improvements in reliability. In a little over two years, 2.4GHz DSS radio control systems have begun to dominate. It is now common to see over 50% of all transmitters in the transmitter pound sporting those little black antennas.

By BOB YOUNG

2.4GHz DSS radio control systems

This Silvertone Flamingo UAV has a 4-metre wingspan, can fly at 95 knots and is fitted with 2.4GHz DSS system.

DSS STANDS FOR "Digital Spread Spectrum", a highly robust radio system that was initially confined to exotic defence communications. Spread spectrum was primarily used by the military in the 1940s and 1950s for communication systems to send and receive secure data. It has only been since about 1985 that it's been available for use by the general public. Now it has come to radio control for model aircraft and it is revolutionising the scene.

The idea for spread spectrum communications originally came from the film actress Hedy Lamarr who conceived and patented a frequency hopping system using something akin to piano rolls. The technology originally could not support this system and the idea lay dormant for many years but was eventually picked up and developed into the modern spread spectrum system.

You can read more about Hedy Lamarr's patent and a lot of other interesting information at **http://www.inventions.org/culture/female/lamarr.html**

As near as I can ascertain, the pioneer of spread spectrum R/C systems was Dave Jones of AUAV, based in Florida, USA. In 2000, Dave began experimenting with Digital Spread Spectrum R/C systems for use in his UAVs (Unmanned Aerial Vehicles). He chose Digital Spread Spectrum (DSS) for its tight security and outstanding ability to reject intentional or unintentional radio frequency interference.

Dave Jones was looking to conduct a flight of a 3-metre UAV to an altitude of 30,000 feet. As you can imagine, one of the biggest concerns was how to ensure rock solid, reliable control of the aircraft. They had planned to conduct most of the flight under autonomous control but still wanted to have the ability to take over manually or make changes in the flight profile should the need arise.

The main concern was that while the aircraft was at those extreme altitudes it could be subject to higher levels of natural or man-made radio frequency interference. Without some form of protection, it would be very easy to lose control of the aircraft, with devastating results.

A likely scenario was that a 72MHz hobby R/C transmitter (72MHz being the legal R/C aircraft band in the USA) could be transmitting on the same frequency in the same locality as the UAV. This could have serious consequences if the autopilot activation switch was turned off due to interference.

AUAV's first approach was a Dual Redundancy R/C system with one link on 900MHz and one on 2.4GHz, with auto transfer from one to the other, if interference or failure occurred on one link. However, after much research, AUAV finally decided to use Digital Spread Spectrum and started developing the forerunner of the DSS R/C systems now being produced and sold to hobbyists the world over.

During the testing phase, a solid-state A/B switching system was used to transfer control of the test aircraft from the experimental DSS system over to a standard 72MHz system; a very sound approach from a safety aspect.

Following AUAV's early success, other manufacturers looked at DSS R/C systems with great interest. Thus 2.4GHz DSS was soon picked up by Spectrum (JR) and others, with low range, lightweight park flyers. After a very successful and relatively short period of introduction, the manufacturers began to produce sets aimed at small R/C sport models and then gradually the size restrictions fell away as manufacturers and R/C modellers alike began to have greater confidence in this new technology.

In fact, in November 2008, the author test flew the new Silvertone Mk.2 Flamingo UAV, using a commercial 2.4GHz direct-sequence DSS R/C system.

One of the really nice features of operating on 2.4GHz is that all of the annoying old bugbears such as servo electrical noise, long lead problems and electric motor interference, etc have all been minimised or completely eliminated. This is by virtue of the fact that the 2.4GHz frequency is far above the noise frequencies and the elaborate encoding/decoding simply obliterates whatever does get through. Hence R/C operation has become virtually problem-free.

How DSS works

Direct sequence spread spectrum, also known as "direct sequence code

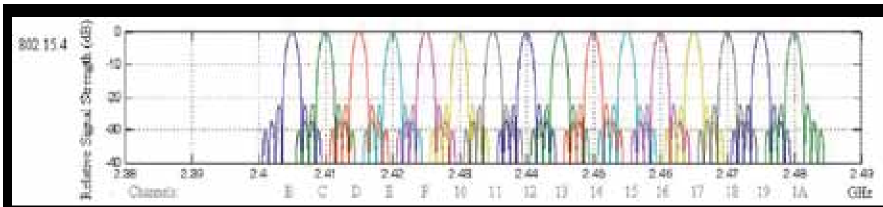
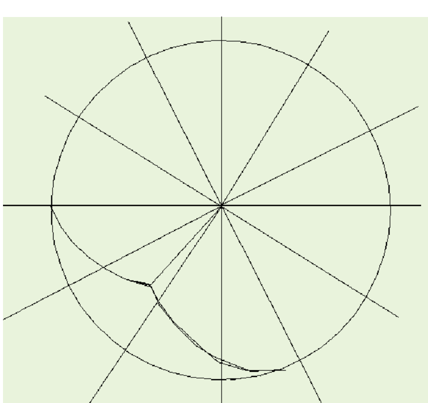


Fig.1: a spectrum analyser display of the 16 2.4GHz channels used in America. The Australian band allocation is a little different.

division multiple access" (DS-CDMA) or DSSS, is the basis for CDMA cellphones and 802.11 wireless transmissions. It multiplies the data bits by a very fast pseudo-random bit pattern (PN sequence) that "spreads" the data into a large coded stream that takes the full bandwidth of the channel.

DSSS is one of two approaches to spread spectrum modulation for digital signal transmission over the airwaves. A data signal at the point of transmission is combined with a higher data-rate bit sequence (also known as a chipping code) that divides the data according to a spreading ratio. The redundant chipping code helps the signal resist interference and also enables the original data to be recovered if data bits are damaged during transmission.

Direct sequence contrasts with the other spread spectrum process, known as frequency hopping spread spectrum or frequency hopping code division multiple access (FH-CDMA), in which a broad slice of the bandwidth spectrum is divided into many possible broadcast frequencies. In general, frequency-hopping devices use less power and are cheaper but the performance of DS-CDMA systems is usually better and more reliable.



This polar response diagram shows two complete orbits of the model – an ideal pass with a perfectly circular response and a slightly heart-shaped response indicating some form of receiver antenna shading in the model.

Frequency Hopping Spread Spectrum (FHSS) continuously changes the centre frequency of a conventional carrier several times per second according to a pseudo-random set of channels, while chirp spread spectrum changes the carrier frequency. Because a fixed frequency is not used, illegal monitoring of spread spectrum signals is extremely difficult, if not impossible, depending on the particular method.

Essentially, spread spectrum is a system in which the data is transmitted across a wide portion of the band or transmitted on a range of frequencies so that interference on one or more frequencies will not degrade the overall system performance to any great extent. This method can be used to make transmissions more secure, reduce interference and improve bandwidth sharing.

DSS systems used in the R/C industry can be divided into two categories: Frequency Hopping Spread Spectrum (FHSS) and Direct Sequence Spread Spectrum (DSSS).

R/C modellers are allowed to use a portion of the 2.4GHz band known as the ISM band (Industrial, Scientific and Medical), along with a myriad of other applications such as WiFi, video transmitters and portable telephones. The allocated ISM band may be divided up arbitrarily by each manufacturer in order to suit their own purposes and it is this fact that makes describing the typical DSS system so difficult.

Advantages of FHSS

There are five main advantages of FHSS:

(1) 2.4GHz band: this frequency is 68 times higher than the 36MHz radios currently used to fly model aircraft in Australia. This in turn allows the use of much smaller antennas on the receiver and higher gain antennas on the transmitter. The high frequency insures that we will not have interference from a 36MHz model radio control transmitter that may be near or on the flying site.

(2) Frequency Hopping: the transmitter and receiver are constantly changing channels by a predetermined pseudo-random sequence, through up to 75 channels to avoid interference from natural or man-made radio frequency interference. For example, if channel 12 has interference on it, the system would only be on that channel for such a short time that the pilot would not even notice a glitch of the controls.

(3) Unique Spread Code: if a second FHSS transmitter is transmitting on the same 2.4GHz band and even using the exact same set of frequencies, the spread code (hopping sequence) would have to be identical as well as time sequence matched to the first system in order to cause interference.

(4) Unique Addressing: each DSS transmitter and receiver pair use unique addressing that is assigned to only that transmitter and any receiver that is bound to it.

(5) Digital Data Format: the control data that is sent over this type of system is true digital data and is for all practical purposes immune to outside interference (in the manner that we use this system). Even if a second FHSS transmitter was transmitting on the same 2.4GHz band with the same hopping sequence, the servo decoder board would still have to receive the exact same digital data in the correct format before any of the servos would move.

Provided the hopping speed is relatively high, the FHSS system offers a very high level of protection and has proven quite successful out on the model fields.

Direct Sequence Spread Spectrum

Depending on the manufacturer's specifications, DSSS divides the allocated 2.4GHz band into a number of discrete channels. It then selects one of these discrete channels and spreads the data across that individual channel. This channel selection may be a fixed selection set by the manufacturer or a dynamic selection after a band search, depending upon the design of the system.

The Zigbee 2.4GHz RF module used in Dave Jones' Infinity radio uses 12 channels. Each channel is identified with its own unique ID number. Each of the direct sequence channels has 65,534 unique network addresses available called the Personal Area Network (PAN ID or chipping code), represented in hex code as 0000 - FFFF. Address FFFF is set aside as a unique address for use during the binding process. This address will never be used in a system for flying – it is only used for the binding process.

In the binding process, it is necessary to set the transmitter and receiver to a common RF channel and a common set of codes. These codes consist of the channel ID number, PAN Address Number, Receiver Destination Address, Transmitter Source Address and the Transmitter's Serial Number.

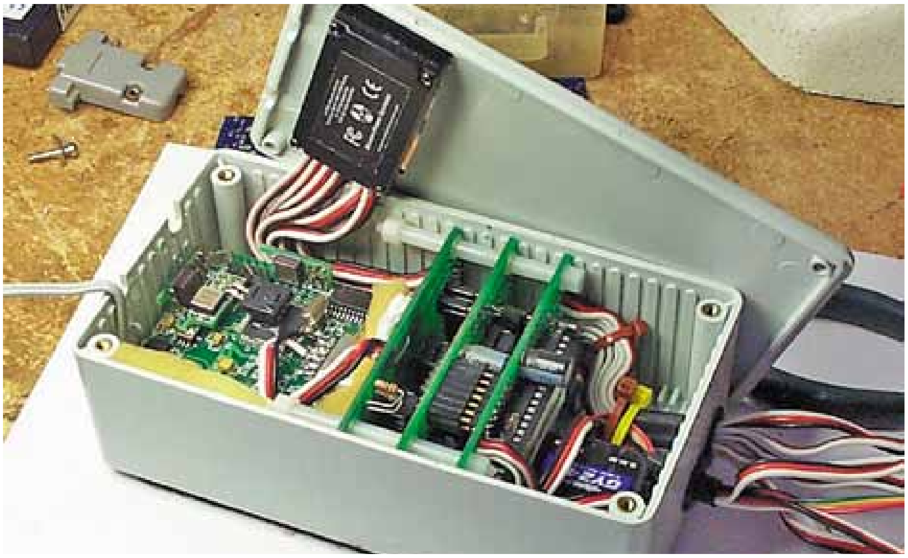
This makes it possible for an unmatched Tx/Rx pair to communicate during the binding process. This process sets both the transmitter and the receiver to a particular RF channel, PAN address and pre-determined destination and source addresses. It also sets the receiver to the transmitter's serial number to get them comminicating.

After communication is established on the set-up channel, the transmitter then transmits to the receiver its own configuration codes that are factory preset. From this point on the Tx/Rx pair are bound via a unique set of codes and will no longer accept data from any other source.

As an illustration of just how secure this system is, let's say that there are12 RF channels that we can use and that each of the four addresses is 16-bit. A 16-bit number can be represented as 0000-FFFF in hex or 0-65,535 in decimal. If we set aside one address from each of the four address blocks for binding, as stated earlier in this article, then we have four unique addresses that will range from 0000-FFFE in hex or 0-65,534 decimal. From here we can do the maths and determine just how many unique combinations of address and RF channels we can have, ie:

RF Channel x PAN x Destination Address x Source Address x Tx Serial Number = 12 x 65,534 x 65,534 x 65,534 x 65,534 = 221,333,908,523,675,812,032.

In operation, the receiver is constantly looking for data assigned only to its destination address. To be valid, this data must contain the PAN ID, the Destination Address the Source Address and the correct Serial Number of the transmitter that the receiver has been bound to. Thus, it is immediately obvious that this is a very secure system indeed.



This view shows the Xtreme Link receiver installed in an autopilot housing. Note the tidy lead arrangement.

The Silvertone autopilot unit with the Xtreme Link receiver.

However, that is not the full story. The magical aspect of DSSS is that when noise is received by the receiver along with the transmitted data, it gets compressed out of existence when the data is decoded and recovered. Because the noise is in real time and the data is expanded across the spectrum, when the data is compressed back to normal the noise simply disappears. Thus, a DSSS system can pull signal out from below the noise floor. It is here that the DSSS system outshines the FHSS system.

Operating 2.4GHz R/C systems

While 2.4GHz DSS R/C systems are great, they do have some new problems and pitfalls. The very high operating frequency has the most far-reaching ramifications. At this frequency, any metal object close to the 26.1mm long antenna can be a hazard. Any relatively large mass of metal or carbon fibre will act as a shield, reflector, director or absorbing element at these frequencies. Even the paint used on the model can function as an antenna shield and so some receivers allow the antenna to be mounted outside the fuselage of the model.

Some manufacturers of R/C equipment also combat this problem with dual-diversity reception, as is now common in WiFi equipment. A diversity set-up allows antennas to be positioned at various locations around the fuselage (providing space

The Futaba 9C transmitter with the Xtreme Link 2.4GHz DSSS module in place of the 36MHz module. Note the small rubber duck antenna.

diversity) and at different polarisation orientations. In this way, at least one receiver can clearly decode data from the transmitter at any time. If using a non-diversity set-up (ie, single receiver), the placement of any conductive objects around the antenna becomes far more critical.

The author recently came across a photo of a 2.4GHz DSS dual diversity installation with figures quoted for the "circular walk-around" (polar diagram) that were very poor. They varied from 86 metres on the lefthand side of the model to 140 metres on the right handside, top 118 metres and bottom 137 metres, giving an overall range variation of up to 61% worst case.

A glance at the installation immediately showed why the results were so poor. The installation featured long metal pushrods passing over the receiver, a badly placed switch harness with long unsecured leads and an antenna coax that ran in parallel to the servo and battery leads.

To cap it all off, the receiver was stuck to the floor of the model with double-sided sticky tape! In a power model, this is one way that's certain to destroy your receiver. Engine vibration is a killer and even surface-mount components will eventually succumb if the vibration level is high enough.

Other measures

2.4GHz signals are also seriously affected by water in all of its forms so be aware that conditions on flying fields will vary from day to day and hour by hour. Wet trees will kill the signal, so do not fly behind trees even for a brief instant.

When installing the receiver in the model keep any metal, carbon fibre or water at least 50mm away from the receiver antenna. Water ballast tanks in gliders, for example, would pose a real threat if near the receiver's antenna.

Any aileron or flap leads dropping into the aircraft's radio compartment present a particular problem, so take special care that any such leads do not move close to the antenna during flight. All leads must be kept well away from the receiver's antenna but the aileron and flap leads on high-wing models pose a particular threat. These are difficult to secure in such a way that the leads remain in place while fitting or removing the wing. Thus, they can move close to the receiver's antenna when securing the wing onto the model and this can go unnoticed.

While on the issue of metal near 2.4GHz antennas, the author also removes the carrying handle from the transmitter as well as the original 36MHz telescopic antenna. The Assan manual, for example, states that it is not necessary to remove the 36MHz antenna but it is a little contradictory to state that metal should not be placed near the receiver's antenna whilst completely ignoring large masses of metal near the transmitter's antenna. In contrast, Extreme Link does recommend removing the 36MHz transmitter antenna.

The rest of the installation follows normal model aircraft procedure but it is recommended that all leads be lashed down to the receiver case with a cable tie or insulation tape to prevent any leads straying close to the receiver's antenna.

Range testing

Once installation is complete, it is time for a range test with the transmitter antenna completely removed.

In keeping with all radio receivers, the higher the receiver antenna is off the ground, the greater the range that will be achieved. Thus, it is important that the receiver's antenna should be set at a constant height from the ground during all range tests. Placing the model on a table, for example, delivers good range and also more repeatability in range testing from week to week as it isolates the antenna from ground moisture that will vary with weather conditions. With the Assan receiver in a small 1.5m high wing model sitting on the ground, a ground range of approximately 60-75 paces is typical.

Then comes the most important test of all – a "circular walk-around" the model. This test is to verify that there are no weak spots in the radiation pattern of the system and in particular, that there are no metal masses blocking the signal path inside the model.

First, place the model on the ground or table and with the transmitter on (in low-power mode, if available) and with the transmitter's antenna removed, walk to the nose of the model. That done, face the model with the transmitter held at waist height and the antenna stub pointing towards the model.

Now walk backwards from the model while operating the controls. Continue to walk out from the model until the servos start to move in a jerky manner, indicating a loss of data packets due to a weak signal. Move in towards the model until solid control is resumed and note the distance.

Now walk around the model in a circle with the antenna stub always pointing towards the model and at the same distance from the model. Note any weak points in the circle where it is necessary to move closer in to maintain solid control. Ideally, you should get a perfectly circular polar pattern.

If the pass is not circular, then rearrange the receiver installation, paying particular attention to the points listed above. Continue to retest until a circular pattern is obtained.

Considering the very low output power of the average 2.4GHz DSS system, the range obtained is excellent. For example, when range testing the Assan system with the transmitter antenna fitted, range was measured at 1.3km on the ground at Waikerie (in South Australia) with the receiver on a small cardboard box 300mm high and fitted with a 6V battery pack. It was not possible to take the transmitter out further due to limitations imposed by the terrain, so range was not tested beyond this point. The green valid data LED was solid green at this range, indicating good signal lock.

Battery packs

Even when operating 36MHz sets, battery packs are the main source of failures. With 2.4GHz DSS systems, battery packs are even more important.

In the early days, DSS systems suffered badly from voltage fold-back due to the cut-off voltage on the front end being set too high by the manufacturers. This has largely been overcome by dropping the voltage cut-off point down to 2.8V or thereabouts. However even now there are still mysteries surrounding the voltage supply to DSS receivers.

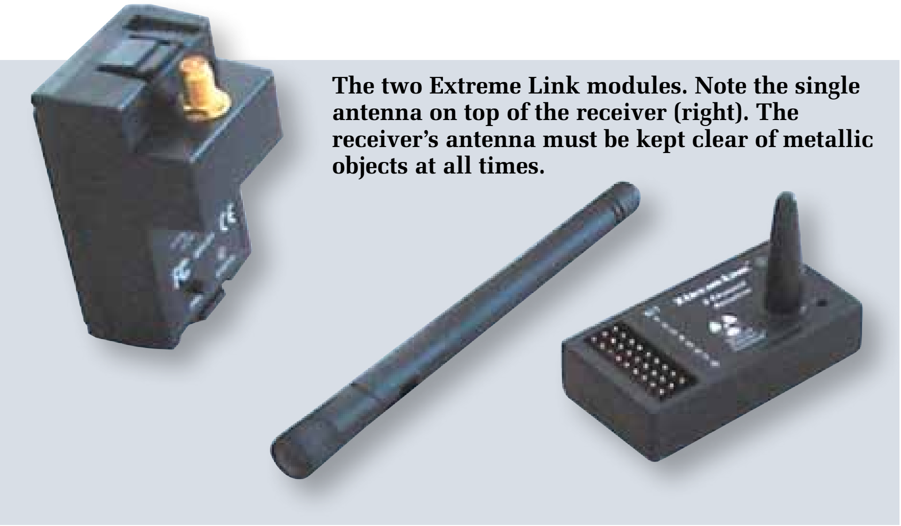
Tests were conducted on an Assan link receiver using a variable voltage power supply with adjustable current limiting. This receiver is interesting in that the manufacturer provides a large electrolytic capacitor fitted with a servo plug and it is recommended that this capacitor be plugged into a spare channel on the receiver.

In a series of tests, seven servos of various types, including one digital, were fitted to an Assan X8R receiver. Servo channel eight was kept clear for the electrolytic capacitor. This was not fitted for the first test. With the servos cycling on at least four channels constantly, the supply voltage was dropped gradually until the receiver stopped working at 2.4V.

The test was then repeated leaving the voltage set at 5V while the current limit was gradually reduced to simulate a battery that could not supply the necessary current. While there was no apparent (or noticeable) variation in the voltmeter, the servos started to slow down and behave erratically. The current limit was then further reduced until the receiver lost lock and the LED started flashing red/green. This test was then repeated but this time with the capacitor fitted to channel 8. This time the receiver did not lose lock even though some of the servos stopped working. The effect of the capacitor was very beneficial in stopping receiver lock out.

The above tests indicate that the internal impedance of the battery is an important factor in receiver operation and a series of antenna-off range checks were carried out with the same receiver to verify this observation.

The range was found to faithfully track the battery capacity, with the higher capacity battery packs delivering a better result. In other words, performance is more in line with battery capacity than battery voltage. Considering that the Assan receiver works down to 2.7V, it is better to use a larger capacity 4.8V battery than a smaller 6V battery.



The two Extreme Link modules. Note the single antenna on top of the receiver (right). The receiver's antenna must be kept clear of metallic objects at all times.

The east-west static display line at the Dalby "fly in" (Queensland).

Flying experience

Non-diversity systems have been flown extensively in several locations in the USA, NSW and, on several occasions, in Dalby, Queensland. One system was also tested in Waikerie, South Australia. During these tests, the systems behaved flawlessly with absolutely no adverse events of any kind.

The Dalby tests included two days of flying with a very large gathering of models at the official opening of the new Dalby Club field. Aerial off range tests were carried out throughout the day with up to seven 2.4GHz systems operating at the same time. No reductions in range, glitching or interference were noted. Flights with many 2.4GHz systems of various brands operating simultaneously were again free of any interference, glitching or any untoward event.

Never at any time has a single non-diversity receiver – whether Assan, Xtreme or Infinity – ever shown any tendency to glitch or behave erratically when fitted into five different models, on many busy club and display days.

From the tests, it is clear that the causes of many of the failures of 2.4GHz systems of all brands revolve around receiver installation, antenna shading and battery problems.

I can only say that I am most impressed with the DSS system and look forward to some very interesting times in the future with who knows what equipment.

Acknowledgement: my thanks to Dave Jones for his invaluable input in explaining DSSS systems. **SC**