Radio Control using

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Model aircraft these days fly at lightning speed and with their backup systems can cost as much as a small car. If someone else's control system blocks yours, the results can be dearly fatal for both aircraft! A new broadband-based system could prove an ideal solution.

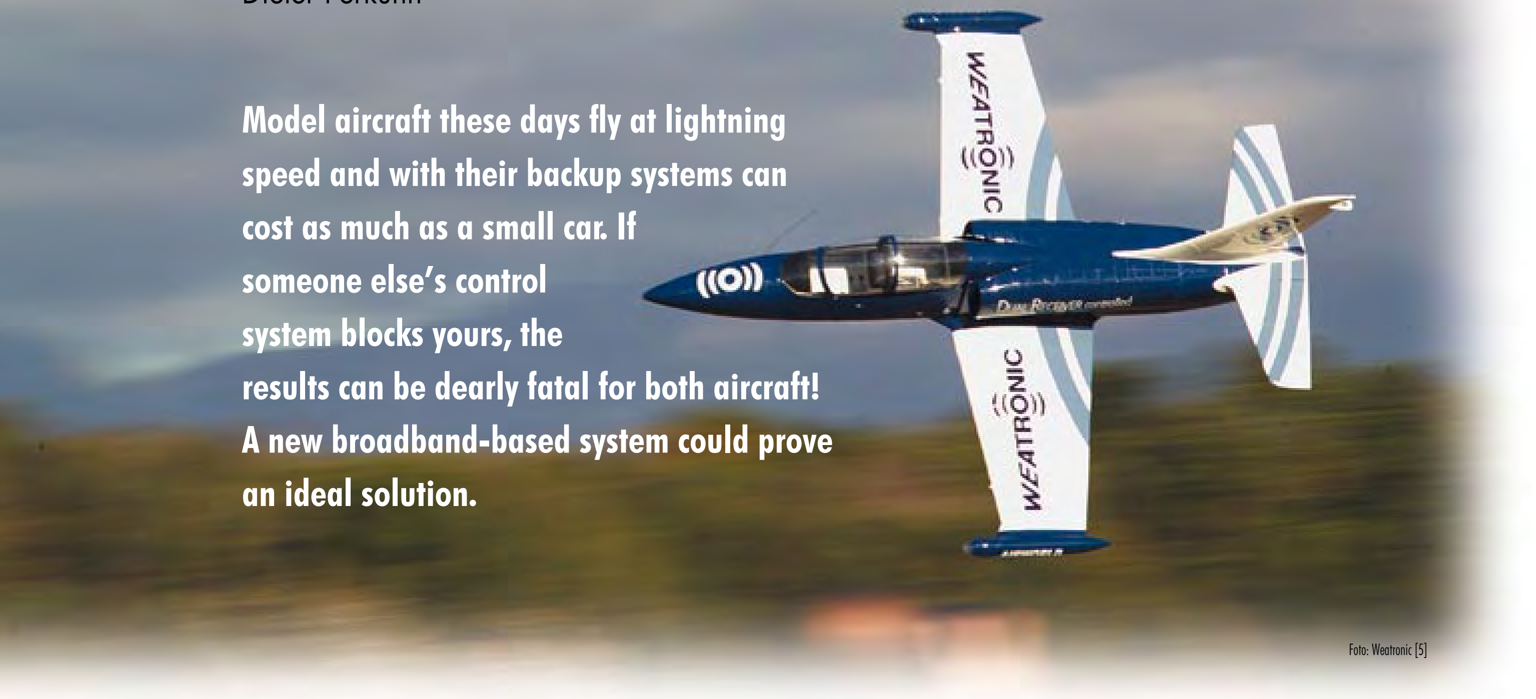

Foto: Weatronic [5]

Until recently it was no exaggeration to describe radio control (R/C) systems for plane, car and ship models as utterly 'stone age', at least from a communications technology point of view. Transmission techniques had not moved forward since amplitude modulation (AM) was generally ditched in favour of frequency modulation (FM), and that was several decades ago. The standards established at that time are largely still in use around the world. Key points of this standardisation include using the frequency bands 27, 35 and 40 MHz for control signal transmission. Across Europe 35 MHz is reserved exclusively for model aircraft control, whereas a multitude of other users have access to the 27 and 40 MHz bands. The frequency bands are divided into channels 10 kHz wide, making this a narrowband modulation system. With no guardbands between individual channels, it is technically simple for signals to bleed over into adjacent channels, requiring signals to be limited to 8 kHz bandwidth if interference is to be avoided. Most of today's R/C receivers use IF filters having a 3-dB bandwidth of around 6 kHz.

The simplest way of generating R/C transmissions is to code the signal using Time Division Multiplex (TDM) technology. To control between 4 (minimum) and 12 (maximum) servo functions, a corresponding number of pulses of variable width are generated sequentially with a repetition rate of around 20 ms, then used to modify the RF carrier using frequency modulation. For this kind of coding the term Pulse Position Modulation (PPM) has been defined. Over the years another system known as Pulse Code Modulation (PCM) has also been implemented and there is no single standard in use. Proprietary (manufacturer-specific) data compression systems reduce compatibility between PCM systems.

Since the signal structure does no more than distinguish between two different amplitude levels, the modulation of the RF carrier boils down to frequency switching between two fixed values. **Figure 1** shows a block diagram of a current model aircraft R/C receiver using double superhet technology. Its architecture conforms to the classic frequency conversion process using a first IF of 10.7 MHz and a second IF of 455 kHz. Signal processing is handled by a microprocessor.

Interference

Unfortunately the interference problem is as old as the remote control hobby itself. Interference in the airwaves is both frequent and destructive, arising from many causes but chiefly through use of the same radio channels by more than one user simultaneously. In severe cases propagation effects can lead to near total signal blocking for a moment or two, although total data loss over any extended period is rare.

Various measures can mitigate the problem of two users occupying the same channel simultaneously. Frequency band scanners built into the transmitters can prevent operation when it is detected that the selected channel is already occupied. This becomes a total solution only when every user's transmitter is equipped in this way, which is seldom the case. The scanner is of no value of course if another user cuts into the channel after the first owner's plane is already in flight.
A higher level of interference protection is achieved by using more than one control channel simultaneously, as in the case of a commercial system that uses one channel each in the 35 and 40 MHz bands at the same time. The possibility of simultaneous interference on both chan-

WLAN ICs

Broadband and DSSS technology for model aircraft

nels is more or less excluded, at the cost nevertheless of increased hardware costs and greater failure risk arising from the higher component count.

A broadband future?

With some model aircraft now using jet propulsion (the heading illustration is a replica of the Albatros L-39 military jet) costing the same as a small car and representing a significant safety risk with air speeds of well over 300 km/h, the desire for fully interference-resistant R/C systems is entirely comprehensible. Unfortunately, regulatory requirements and the need for backwards compatibility are hindering the introduction of any fundamentally new R/C technology. On the other hand practically proven communication techniques have existed for a long time that would adapt to model control extremely well. Examples taken from mobile radio include the DECT, WLAN, Bluetooth and ZigBee standards. In all these applications a multitude of point-to-point or user device-to-user device radio links are operated bi-directionally and simultaneously in the same frequency domain.

The American Paul Beard and his firm Spektrum have developed a radio R/C system for models that exploits modern communication techniques and takes full advantage of cheap, off-the-shelf chipsets [1]. The initial offering, for R/C car models only, was RF modules for three servo functions. This was a far cry from the latest product, a fully airworthy system covering six servo functions with the code number DX6. **Figure 2** shows the transmitter and receiver. The only restriction is that this control system is intended only for so-called parkflyers and micro helis. These craft have a range of 100 metres maximum.

The technology

Spektrum's R/C system operates in the 2.4 GHz ISM (industrial, scientific, medical) frequency band that is available for use without a user licence in most countries. Consequently it is used by a multitude of applications including WLANs, Bluetooth and ZigBee. The effect of these other applications is of minor significance to us, since in the vast majority of cases the physical distance or separation between these indoor users and our outdoor R/C systems will be large enough to cause no difficulty. The generous breadth of spectrum at our disposal, around 83 MHz (from 2.4 to 2.4835 GHz), enables modern digital modulation techniques to be used to their best advantage. Regulatory conditions lay down a spectral power density of 10 mW per MHz of bandwidth, capped at a maximum of 100 mW for the complete band. Depending on the bandwidth of the signal being radiated, transmit powers of between 10 and 100 mW are permissible. A purely theoretical calculation indicates a potential transmission range of over 10 km with 100 mW transmit power, –90 dBm receiver sensitivity and 6 dB antenna gain at transmitter and receiver—or 4 km using 10 mW. In a radio controlled aircraft context several conditions would have to be guaranteed to achieve this kind of range and experience with WLANs and Bluetooth indicates the dis-

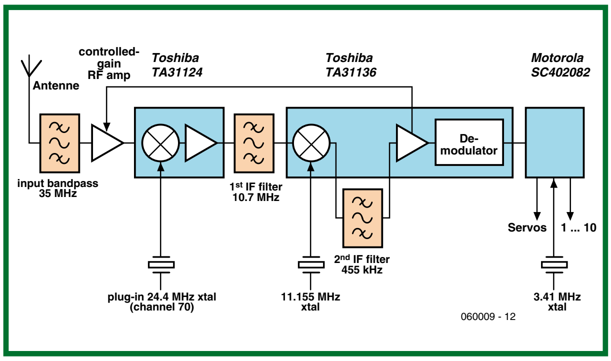

Figure 1. Block diagram of a conventional remote control receiver for model aircraft (Photo: author).

Figure 2. DX6 2.4 GHz model aircraft transmitter with receivers for six servo functions (Source: Graupner [6]).

Figure 3. Transmit RF module and receiver for remote control of model cars (Photo: author).

tances achieved in practice are frequently well below the theoretical values.

To establish what might be realistic results, range tests were carried out using transmit and receive modules made by Spektrum for radio-controlling model cars (**Figure 3**). In these tests the transmitter and receiver were positioned around 1.5 metres off the ground (flat landscape, ground covering damp, transmit and receive antennas in direct line of sight with around 800 m separation). Under these conditions the link was rock-solid, without any interference at all. However, as soon as either transmit or receive antenna were blocked by human bodies the link was lost altogether.

The Spektrum transmit module has an output power of 10 mW and thus conforms to specification ETS 300 328 for GSRDs (General Short Range Devices). By way of comparison, data sheets for commercial WLAN routers indicate they provide radiated power levels of 15 dBm (equivalent to 31.6 mW), as they occupy a greater bandwidth.

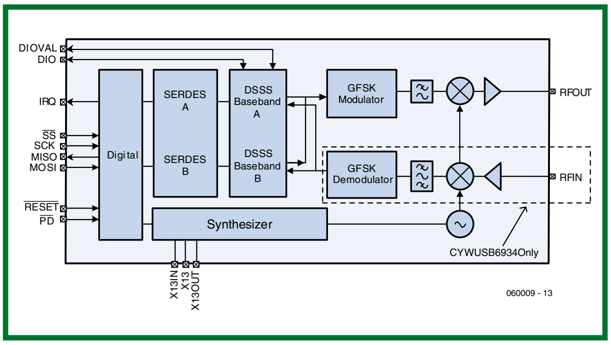

Figure 4. Simplified block diagram of the Cypress CYWUSB6934 transceiver (Source: Cypress).

Chips with everything

At the heart of Spektrum's transmit and receive modules is the CYWUSB6934 transceiver made by the U.S semiconductor producer Cypress Semiconductor Corporation [2]. Receive sensitivity is –90 dBm (7 µV into 50 Ω) and transmit output power is 0 dBm (1 mW). Integrated with this is a 13 MHz reference oscillator for the internal frequency synthesiser. The oscillator is voltage-controlled so that it can cover the complete 2.4-GHz ISM band. Its circuit architecture reveals a single superhet with low IF and integrated IF filter (**Figure 4** gives a simplified block diagram). According to the manufacturer the module is intended for cordless applications in PC mouse, keyboard und joystick applications, for game controllers, remote controllers, barcode scanners and toys. To achieve the output power of at least 10 dBm (10 mW) required for remote control of models, the transmit module uses an SE2526A power amplifier from SiGe Semiconductor [3] to boost the signal. This amplifier module is normally used in WLAN applications built according to IEEE 802.11b and g specifications that provide RF output levels up to 20 dBm (100 mW). The chip has an integrated low-pass filter and an antenna changeover switch that makes separate transmit and receive connections possible. The transmit antenna is well matched and is connected using 50-Ω coax cable. Whether Spektrum actually limits the output to 10 dBm would need precision measurement to establish but the power is certainly appreciable. The author's tests were confined to making relative measurements. In this process the transmitter was switched on and off many times at random so as to test occupancy of all possible 79 RF channels in the 2.4 GHz ISM band. The total frequency range covered was determined at around 84 MHz, which squares up well with the permitted bandwidth of 83 MHz. The band occupancy of the signal in use in one of the 79 RF channels was around 830 kHz, corresponding to the channel spacing of 1 MHz.

Construction and layout of transmitter and receiver printed circuit boards are shown in the following pictures. In **Figure 5** the transmit RF board can be seen together with the subminiature co-ax socket for the antenna connection. The track from the connector to power amplifier chip has an impedance close to 50 Ω. Near the edge of the board is the 13-MHz reference oscillator for the transceiver IC. **Figure 6** shows the transmit signal processing board with its microprocessor and clock oscillator, **Figure 7** illustrates the receiver RF board with the transceiver. The simple wire antenna, which is not impedance-matched, is taken direct to the receiver input with filtering. Finally in **Figure 8** we see the signal processing board for the receiver, complete with microprocessor and clock oscillator. With no adjustable filters used in either the transmit module or the receiver, construction is both straightforward and affordable. The VLSI chips used have a unit price of less than five dollars (n quantities of 100 upwards).

Management matters

Organisation of signal generation and processing is handled in both the transmit RF module and the receiver by a Cypress CY8C27443-24PVI microprocessor [2]. The Cypress transceiver is configured so that it operates in one of the 79 possible channels within the 83 MHz wide 2.4-GHz ISM band. To achieve this, a scanning process is initiated when the device is powered up. This means that the Spektrum transmitter operates bi-directionally; the receiver associated with the transmitter scans the band and gives the go-ahead to the transmitter only when an unoccupied channel is found. To avoid mistakes the transmit/receive management system ensures that the devices do not transmit and receive simultaneously. Test measurement show that the transmit signal is pulsed with an 'on' time of just over 5 ms and 13 ms repetition rate.

The signal used to control the servo functions is not in fact modulated directly onto the RF carrier. Cypress makes use of a digital modulation system by the name of DSSS (Direct Sequence Spread Spectrum) [4]. This is one of two prominent digital modulation techniques, the other being FHSS (Frequency Hopping Spread Spectrum). DSSS is used in WLANs, ZigBee, GPS and UMTS, with FHSS employed by Bluetooth. Both techniques have their roots in the military field. The FHSS technique involves signal-hopping among the 79 channels of the ISM band 1,600 times a second, following a fixed sequence determined individually between each transmitter and receiver.

Military origins

The remote control system that we are using employs DSSS. In the process the narrowband desired signal is first processed digitally so as to straddle a significantly broader bandwidth and is only then modulated onto the RF carrier. In this way the spectral power density is reduced to a level where the spread-out transmit signal disappears into the general noise background and can no longer be detected using conventional methods (the military connection now becomes clear). The receiver, if provided with the same code, can reverse the spread process using what is called 'processing gain'. The gain here increases as the straddle code ('chipping sequence') becomes extended. Any transmitters using the 'wrong' code will be heard as noise and ignored. It's not all gain, however, and there are nevertheless limits that are set primarily by the limited processing power available. The bitrate change of the chipping sequence used by Spektrum for remote control amounts to 64 chips/bits corresponding to a calculated gain of $10\log_{10}(64)$ = 18 dB. Various losses reduce this in practice to perhaps 16 dB. To achieve an acceptable signal-to-noise ratio of circa 10 dB and system losses of around 2 dB for good resistance to potential interference a signal processing gain of more than 30 dB would be required. In a situation like this the power of the interfering signal might be 20 dB stronger than the wanted signal. This, however, would imply a bitrate change or chipping code length of more than 1,000. It's easy to see how the system parameters for really good interference suppression run rapidly out of control. It's worth noting in addition that this process can work only when transmitter and receiver use the same code. With Spektrum's remote control the transmit code is made known to the receiver at the start of operation using the so-called 'binding process' (it's just conceivable that other receivers might be linked in too!).

Finally, here's an interesting thought to consider: for data transmission this new system employs one out of 79 channels each 1 MHz wide and prevents another user of the same system from sharing the same channel. Resilience to interference in the same channel is nevertheless minimal if a more powerful user employing another system appears. The WLAN system on the other hand employs three channels each 22 MHz broad and permits a limited number of devices using the same system within a single channel. And on account of the significantly greater channel bandwidth, WLAN is significantly more resistant to same-channel interference. It is nevertheless accepted that increasing user numbers in a channel reduces the data rate. This selfsame criterion is not acceptable for radio control, however; real-time response takes top priority. This is presumably the reason why Spektrum employs the system described, even though it is less interference-resistant. A further pointer in this direction is the fact that the new DX6 remote control for model aircraft actually occupies two out of the 79 channels simultaneously and the receiver is also built on a twin-channel basis (**Figure 2**). It would be fascinating to learn how remote control systems of this kind perform when several users are using the same type of equipment concurrently.

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Web links

[1] www.spektrumrc.com

[2] www.cypress.com

[3] www.sige.com

[4] http://en.wikipedia.org/wiki/Direct-sequence_spread_spectrum

[5] www.weatronic.com

[6] www.graupner.de

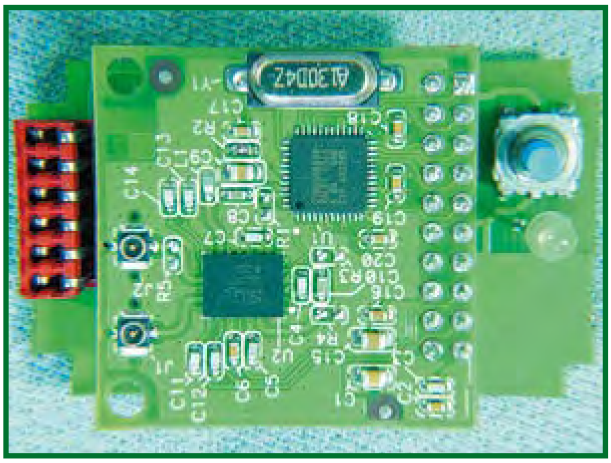

Figure 5.
Transmitter RF board with subminiature co-ax connector for antenna connection. The circuit track from the connector to the transceiver IC has an impedance close to 50 Ω (Photo: author).

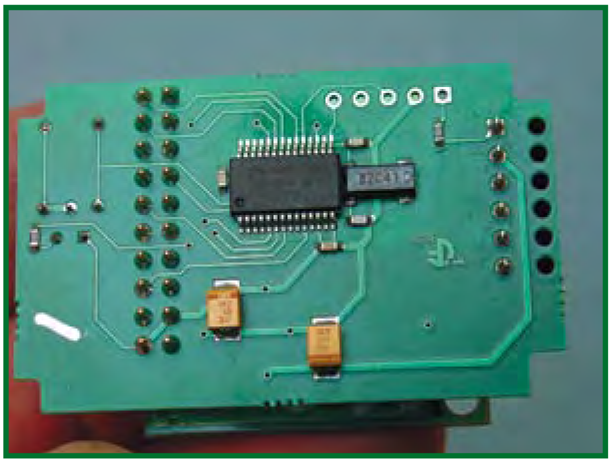

Figure 6.
Transmitter signal processing board with microprocessor and clock oscillator.

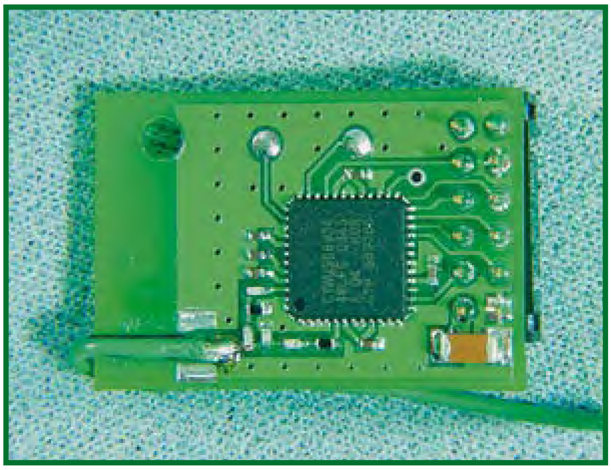

Figure 7.
Receiver RF board with transceiver IC. The simple wire antenna, which is not impedance-matched, is connected direct to the receiver input without filtering.

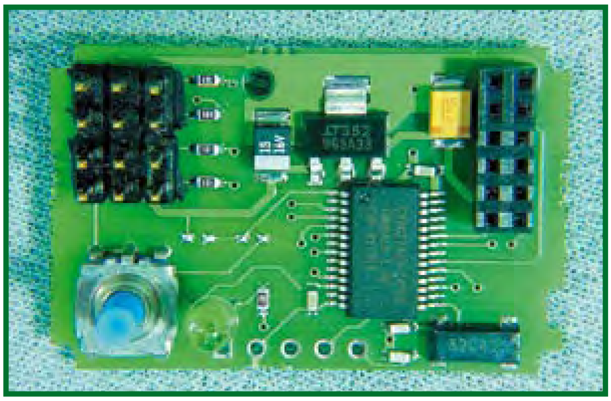

Figure 8.
Receive-side signal processing board with microprocessor and clock oscillator.