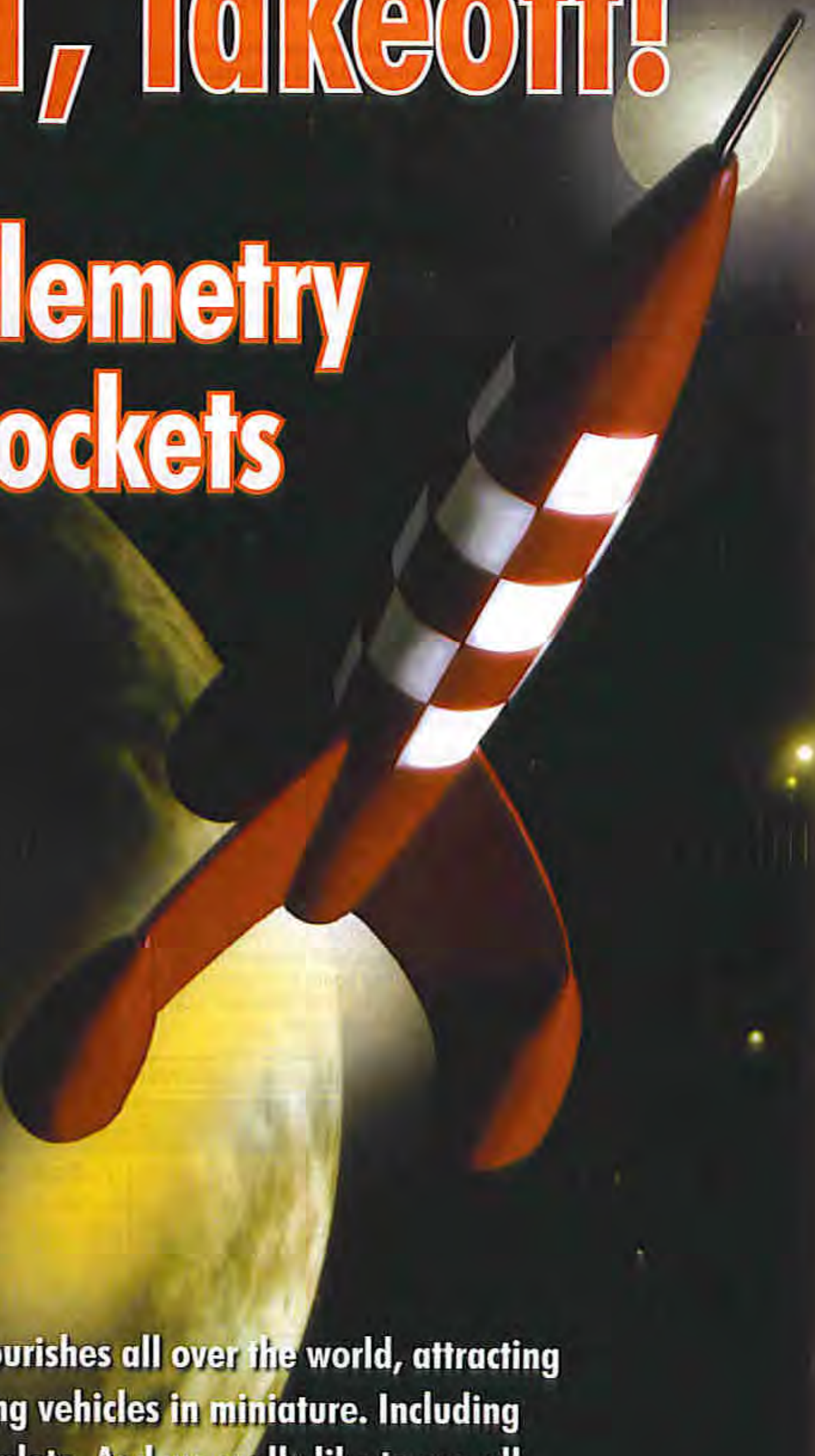
...3, 2, 1, Takeoff!

Over-air telemetry for model rockets



Mike Bessant

Model construction as a pastime flourishes all over the world, attracting people with an interest in replicating vehicles in miniature. Including rockets — fully functional and complete. And we really like to see all sorts of flight data (telemetry) too. But how do we get hold of this data, when the rocket is soaring off at an altitude of 500 m or more? A cable is not an option. This circuit nevertheless shows you how to do this. Telemetry is taking off, literally!

The amateur rocket building community in Europe grows at a steady pace. According to a US agreement there is a distinction between two separate groups: those that occupy themselves with model rockets and those that work with high power engines. The vast majority of launchings fall in the category of model rockets. That is because high powers demand stringent safety requirements and relatively expensive materials.

A standard model rocket vehicle kit can be found in hobby shops from about £ 25, including the disposable engine. More advanced models that use a cluster engine to lift a usable cargo ('payload' in space terms) hundreds of meters or even a few kilometres into the sky can stimulate electronics enthusiasts with all kinds of interesting challenges. Applications range from aviation technology to environmental monitoring.

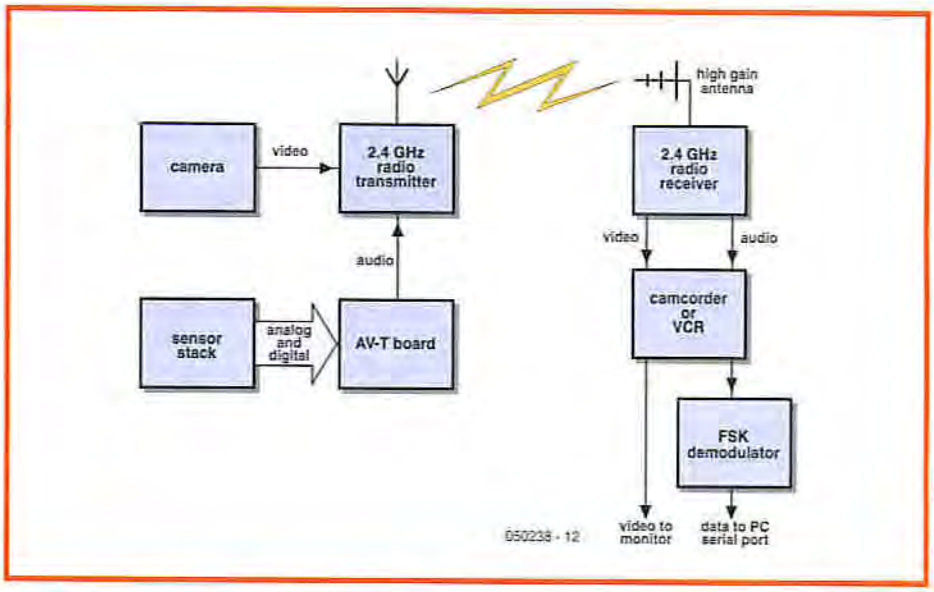


Figure 1. Block diagram of the air borne (hopefully skyborne!) telemetry system.

On board

An example of a payload is described here. The system can transfer information from the sensors wirelessly to a ground station. The starting point is a real-time video link. Aside from the high entertainment value of on-board video images, they also contain useful information regarding various flight data such as rotation speed, highest point, time instant of parachute deployment, etcetera. This data can also be related to data from other sensors that are on also board.

The audio channel of the video link proved to be eminently suitable to send the sensor data. The result was better than that obtained from using a separate transmitter. The audio and video signals are received on the ground and stored on a portable video recorder or a camcorder for further analysis on a PC. Data storage on board of the rocket is also a possibility of course, but if something goes wrong you would really like to be able to access this data. It is usually the case that those rockets that have something wrong with them are the ones that end in fireworks, at which point the data stored on board cannot be rescued any more. A second advantage of using a transmitter is that the rocket can be easily found after landing, using a directional antenna.

Figure 1 shows the block diagram of the telemetry system. The part that flies with the rocket is contained on one circuit board that fits in a standard 6 cm model rocket tube. One side of the Airborne Video Telemetry (AV-T) board is fitted with the telemetry components, while the other side contains the camera and transmitter module (see **Figure 2**).

The AV-T board has a versatile sensor port and can be configured for a large number of analogue and digital sensors using the BASIC programming language. The sensors and their signal conditioning electronics are fitted on several stackable printed circuit boards that are interconnected with a ribbon cable. **Figure 2** shows that the sensor boards are perpendicular to the main circuit board. In this way, sensors such as accelerometers and gyroscopes are correctly aligned with the longitudinal axis of the rocket. A typical payload would consist of one or more of the following sensors: accelerometer, gyroscope, barometer, Hall-sensor and GPS receiver.

Picture

The selection of a usable camera is determined by working backwards from the video standard of the recording system on the ground. We have assumed a PAL TV system, but the principle is the same for other standards. There is now a large choice of miniature full-colour cameras that can be bought for less than £ 75. Cameras based on CMOS technology are usually cheaper, use less energy, but are generally not as good as their CCD counterparts.
During the flight the camera is subjected to continually changing light conditions. The rocket rotates around its axis and turns around at the highest point. In order to get pictures of reasonable quality it is best to choose a camera that is fitted with automatic

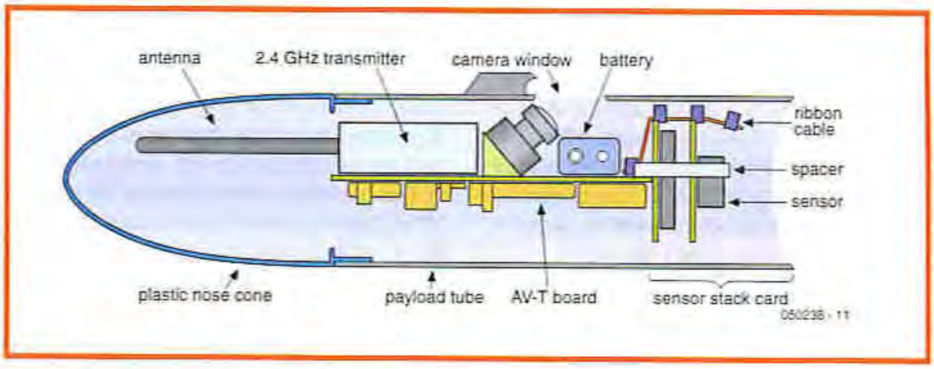


Figure 2. Cutaway view of the payload, showing an example of construction inside the rocket.

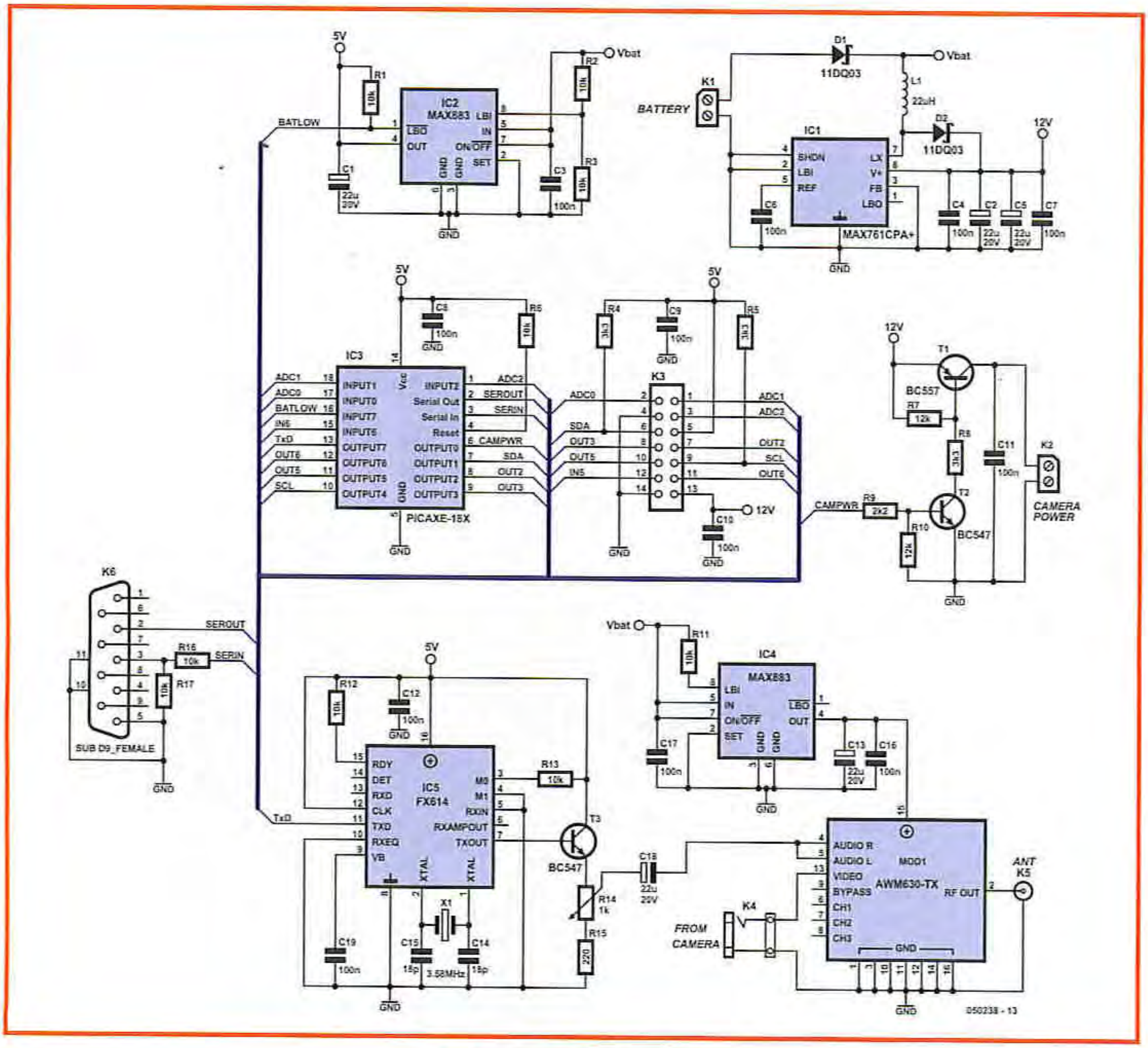


Figure 3. Circuit diagram of the AVT circuit board.

gain control (AGC), electronic shutter speed (AES), white balance (AWB) and backlight compensation (BLC).

A standard PAL TV camera including the lens will easily fit in a cube with 3 cm sides. The weight will be about 10 grams and the camera will be happy with 50 mA at 12 V. The standard resolution amounts to 380 TV lines and the output is typically 1 V_{pp} into 75 Ω. Three wires suffice to connect the camera: power supply, video-output and ground.

Transmitter and antenna

An easy way to transmit live video over a few hundred meters (vertically) is to use cheap transmitter and receiver modules intended for consumer applications such as security cameras and TV video links. Most of these modules use the Industrial, Scientific and Medical (ISM) band at 2.4 GHz. A standard video transmit module weighs about 15 g and has dimensions of about 1×3×4 cm. The current consumption of the module is also around 50 mA at 12 V. The output will be in the region of 10 mW into 50 Ω via an SMA connector. Four signal wires are generally enough: (video and audio inputs, power and ground). If the camera and transmitter module use the same video standard then the output of the first can be directly connected to the input of the second.

Rules

National organisations such as OfCom and DTI in the UK, or FCC in the US, look after the rules for the ISM bands, so that only products that comply with these rules are permitted. These rules vary from country to country and it is the responsibility of the user to use only equipment that complies with the requirements of the country it is used in.

An example of a restriction is that the antenna in the ISM band is not allowed to have any significant gain. So an omnidirectional antenna has to be used. This type of antenna radiates the same amount of energy in all directions. Fortunately this is just what we need for this application. Omni directional ¼λ whip antennas that fit directly to an SMA connector are readily available. It is ideal if the antenna can be fitted in the plastic nose cone of the rocket, located as far as is possible from the circuit board, the batteries and other metal objects.

AV-T board

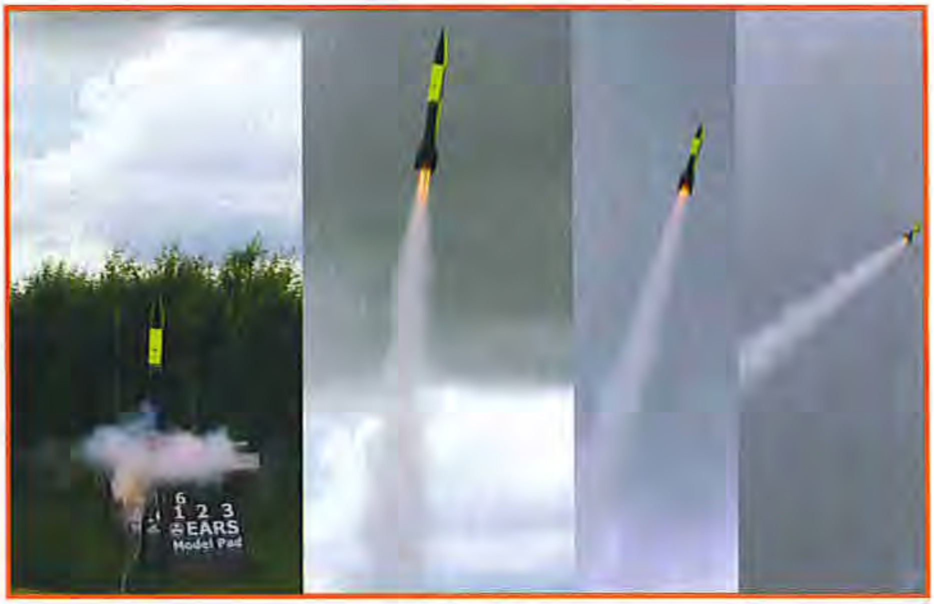
Figure 3 shows the schematic of the Airborne-Video-Telemetry-system. The circuit uses a PICAXE microcontroller (IC3). The PICAXE family consists of PIC Flash microcontrollers from Microchip which are pre-programmed by a company called Revolution Education Ltd (REL) with bootstrap code. With this code, the PICAXE microcontroller can be repeatedly programmed in BASIC with a simple 3-wire connection to the serial port of a PC. In this way, a conventional In-Circuit-Programmer (ICP) is not necessary.

The PICAXE family comprises 8, 18, 28 and 40-pin versions that REL sells for about the same price as that of a one-off unprogrammed PIC.

The AV-T uses a PICAXE-18X (the bootstrap code indicates that it is a PIC16F88). In addition to the standard general-purpose I/O-lines, the IC contains three 10-bit ADCs, an I^2C bus and a UART port. The AV-T has a serial port to support the ICP and software development with the PICAXE Programming Editor [1]. This Windows program has a version of BASIC that supports many special interface commands (readadc, count, pwmout, readi2c etc.). This greatly simplifies the development of the software and the testing of the sensors. The internal PICAXE clock can be programmed to run at either 4 or 8 MHz. This corresponds to about 10 k or 20 k BASIC instructions per second. The non-volatile memory of the PICAXE can hold about 600 lines of BASIC code.

The FX614 (IC5) is an FSK-modem (Frequency Shift Key) that has been designed for communications using asynchronous data at a speed of 1200 bps (bits per second). In the transmit mode, which is controlled by the AV-T, two discrete frequencies are produced at the output. These depend on the level of the logic signal at the serial port of the PICAXE. A logic zero results in 2200 Hz and a logic one in 1200 Hz. This FSK signal consists of a sinewave with low distortion and has continuous phase when transitioning between the two frequencies. In this way unwanted higher harmonic frequencies are avoided at the audio input of the video transmitter. These generally have a bandwidth from 50 Hz to 10 kHz. The amplitude of the FSK signal can be adjusted with P1 to maximum modulation but without causing distortion or interference with the video signal. For the transmitter module we use an AWM630-TX from Saelig.

The dimensions of the AV-T PCB are determined by the diameter of the rocket, together with the dimensions of the video module, camera and battery. This results in a reasonably large PCB of 6 by 13 cm (see **Figure 5**). As



Author's rocket at various launch stages..

a result the prototype could be built with standard components. The PCB artwork files can be downloaded from www.elektor-electronics.co.uk

During the launch the circuit board is subjected to an acceleration of several g ($1\ g = 9.8\ m/s^2$). The leads of some components could bend as a result, for example those of an axial tantalum capacitor. It is best to fix those components that are sensitive to this in place with silicon adhesive.

Power supply

The MAX761 (IC1) step-up switch-mode power supply delivers a regulated 12 V/150 mA at a minimal input voltage of 5 V. A 9-V PP3 battery is therefore eminently suitable as the energy source for the video camera and the transmitter. After the rocket has landed, the PICAXE switches off the camera power supply (via T1 and T2), but leaves the transmitter module powered up. The rocket can then be easily found by tracking the transmitted signal. The battery is therefore loaded with the maximum load for only a few minutes.

The MAX761 uses a switching frequency of 300 kHz. In this way the efficiency remains reasonably high. A disadvantage is that at this frequency extra attention has to be paid to the PCB layout and the choice of components. L1, in addition to having a ferrite core, needs to have a saturation current of more than 1 A and a DC resistance of less than 0.1 Ω. To limit radiated energy, toroidal cores, pot cores or shielded inductors have to be used. Diode D2 needs to be a high-speed 1 A Schottky diode. The prime consideration for the output capacitors C2, C4 and C5 is a low series resistance (low ESR). That is because ESR is the main cause of ripple in the output voltage.

In addition to the AV-T circuitry, the MAX883 (IC2), a low-drop, 5-V regulator IC also provides the power for the sensors that are connected to the ribbon cable. Depending on the battery

DESIGN CONTEST: Sky-rocket your own design!

Elektor Electronics and NERO (Dutch federation for Rocket Research) together have organised a design contest for an interesting payload that, based on apparent suitability, will fly on the rocket that will attempt to break the European altitude record in 2008. In this attempt it is the intention to reach an altitude of no less than 40 km.

NERO has occupied itself since 1959 with the design, construction and launching of amateur rockets. In the past, NERO has bagged a number of records: the highest amateur rocket flight in the Netherlands, the first European flight with a hybrid motor and the first Dutch two-stage rocket flight. Rocket amateurs from NERO are busy with a project to break the European altitude record for amateur rockets. A project team of 14 people is busy with the design and construction of a two-stage rocket that will have to turn this into reality in 2008. The goal is to take the UK altitude record, that stands at over ten kilometres, to the Netherlands and improve it by about thirty kilometres.

The submitted design needs to contain an interesting experiment (for example measuring the Earth's magnetic field with sensors or measure rotation based on the sun's position). The mechanical and electronic requirements that the design has to comply with can be downloaded from the Elektor Electronics website [3].

The submission must comprise an electronic as well as a mechanical design. In addition the design needs to pay attention to:

- **the method of testing, qualifying and calibrating on the ground;**
- **the method of activation in the rocket;**
- **the method of protection against vacuum and condensation;**
- **the relevance of altitude for the experiment;**
- **the method of storage and retrieval of the measurement data.**

A winner will be chosen on the basis of the submitted designs. The winner may let the design fly on a qualification flight in the Netherlands. If the design is deemed suitable for launching with the altitude record rocket (safe enough, light enough and reliable enough) then launching with the altitude record rocket becomes an option. Due to air traffic regulations the altitude record will take place outside the Netherlands — the exact location is not known yet. Scandinavia or Poland are under consideration. A complete ground station will be built on location, complete with tents, generators and assembly facilities.

Designs need to be submitted to Elektor Electronics before 1 July 2007 (send to Elektor Electronics, Regus Brentford, 1000 Great West Road, Brentford TW8 9HH, England, mentioning 'Rocket Contest').

The rocket that will be built for the record attempt is called H10. It will have two motors with a total thrust of 26,000 Ns. These motors will give the rocket an initial acceleration of 15 g and a maximum speed in excess of Mach 3. Several qualification flights – where the developed components will be tested – will be carried out in the Netherlands, before an attempt is made to break the record abroad. More than 400 mechanical parts will be especially manufactured to make this flight possible.

The rocket is also subjected to extreme environmental conditions in the stratosphere. Aerodynamic heating of the nose cone up to 300 degrees, ambient temperatures of –60°C and an air pressure of less than 1% of the air pressure at ground level. Two parachutes, a pilot parachute and a main parachute ensure a soft landing. The decoupling system of the first stage and the opening of the parachutes are driven with the aid of pyrotechnics.

A remarkable aspect of this record attempt is that this rocket will fly with complete instrumentation to this altitude. So, for example, a GPS module, a video camera and a transmitter will be taken along. The central board computer compares the information from several sensors in order to determine the reliability of the sensor data. Both the video images from the rocket as well as the data collected by the board computer will finally be transmitted to the ground station using a powerful transmitter.

The ground station receives the video and data signals. Three antennas are used for this. The purpose of the first antenna is to receive the signal during the first part of the flight. The second antenna is mounted on a platform with two degrees of freedom and uses the received GPS signal to point the dish antenna to that part of the sky where the rocket is. The third antenna serves as backup and is able to receive during the last part of the flight – just before the landing. The strongest signal from the three antennas is selected and split across three computer monitors. The first screen will show the real-time video signal from the rocket, the second screen a map of the surroundings with the position of the rocket superimposed and on the third screen vital information regarding the functioning of the board systems of the H10 and the actual altitude of course!

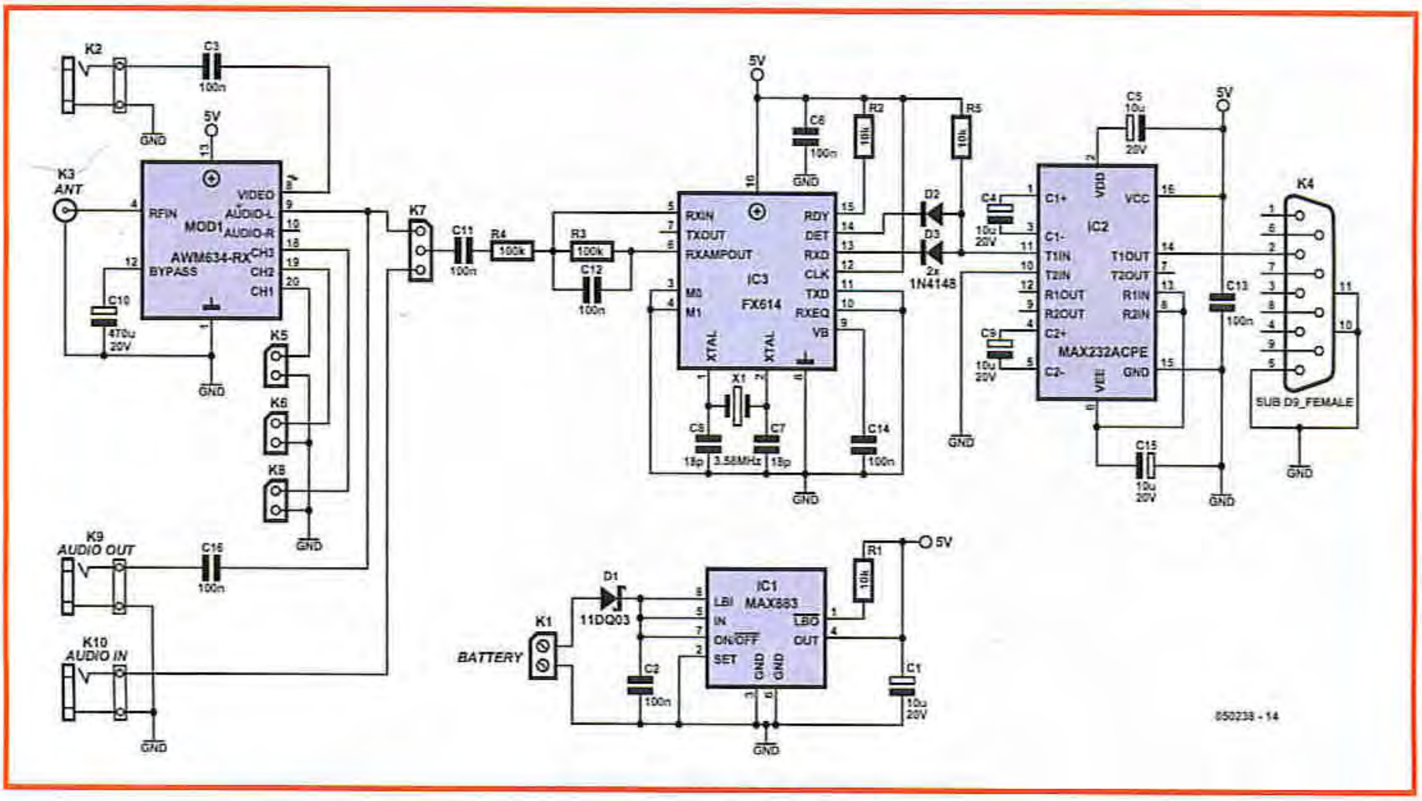


Figure 4. Circuit diagram of the 2.4 GHz receiver and the FSK demodulator.

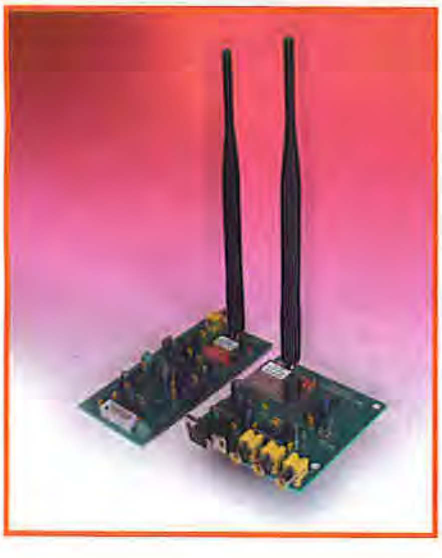
that is used, the MAX883 can deliver more that 100 mA. Output $\overline{LBO}$ goes low when the input voltage drops below 6 V. The PICAXE checks the output from the MAX883 and can generate a warning when the battery voltage is too low. The transmitter module has its own regulator (IC4).

Ground station

At the receiving side there are no limitations with regards to the antenna used. So we can use a Yagi directional antenna with high gain. The range through the air (in a straight line without any obstacles) can then amount to several kilometres. The greater the number of elements on the Yagi, the larger the range and directional sensitivity. But since the antenna has to be pointed manually towards the rocket, high directional sensitivity and large size are not convenient.

There are plenty of choices for cheap ISM video/audio receivers and most of them can be easily attached to the base of the antenna to limit the cable losses at 2.4 GHz.

The circuit that is mounted on the antenna (**Figure 4**), uses a small Airwave AWM634-RX module that is powered from a battery and a 5-V low-drop voltage regulator (IC1). Jumpers K5, K6 and K8 are used to select one of the four standard frequency bands. K10 allows an external audio signal to be connected. K7 allows the choice whether the direct signal or the external signal is connected to the FSK-demodulator. The received video signal is available



Firmware

Our telemetry system has no firmware — the idea being that you write it yourself to match the sensors you wish to use. This is unlikely to cause problems as the programming language used on the PICAXE micros is really simple.

The programming language also contains sufficient resources and support for signal measurement and the use of the I2C bus, making application software writing a breeze, really.

To simplify copying your own software into the PICAXE, the transmitter circuit is equipped with a programming interface. The circuit is connected to a PC via an RS232 cable, whereupon the software can be transferred in a simple manner.

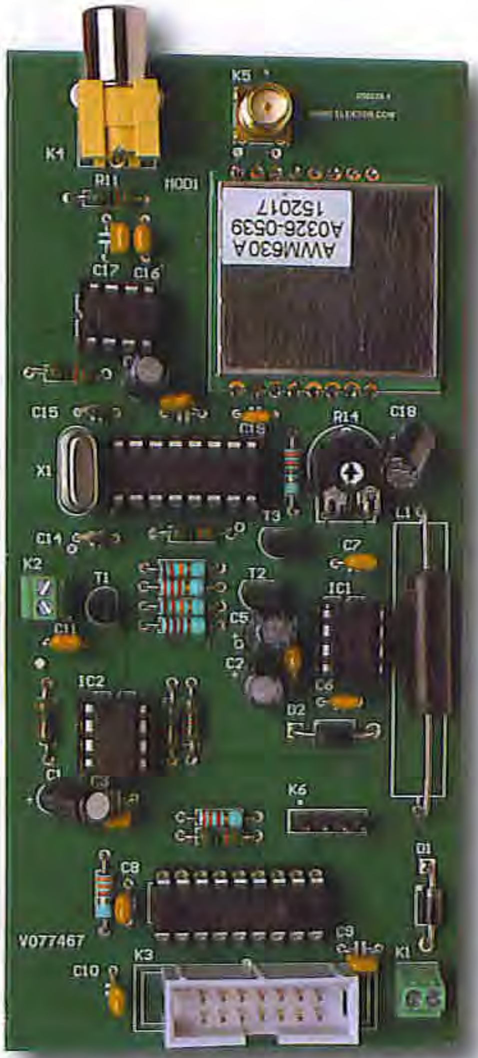
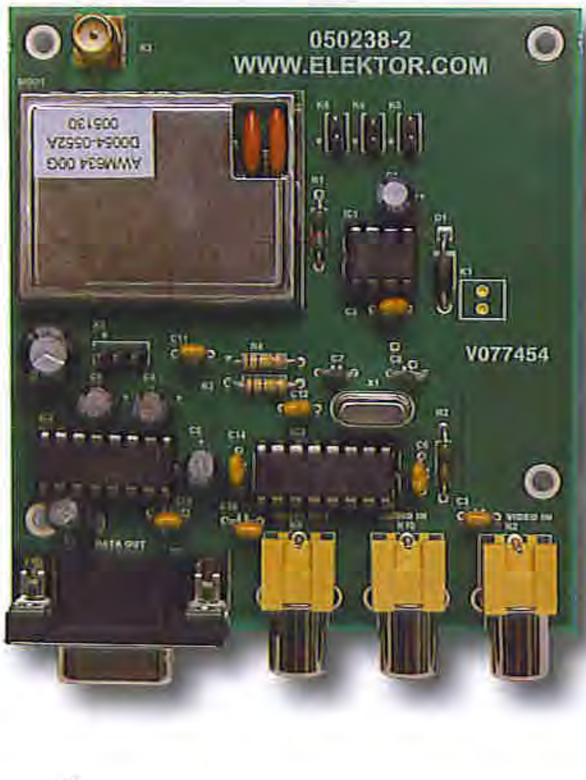


Figure 5. Components mounted on two of our prototype boards. Above: transmitter; below: receiver.



on the outside on K2.

The demodulator circuit for the data is based on the same chip as that used on the AV-T board, the FX614. In this circuit however, pins M0 and M1 are set so that only reception is enabled. The demodulator has an input amplifier and a band-pass filter. If the signal drops below a certain reference level the DET-output prevents erroneous data from being sent to the serial port of the PC.

To record the data it is best to use a camcorder with an S-video input. The video signal can be played back on a TV and the demodulated audio signal can be connected to the serial port. In this way synchronised video and data can be examined.

SelmaWare Solution's StampPlot Pro software generates nice charts from data received via the serial port. This Windows application accepts data as a string or as binary values with up to ten channels. The program has many powerful options that can store raw or processed analogue and digital data, attach a time stamp and display it on a chart. A free evaluation version can be downloaded from the SelmaWare website [2]. You can also find a number of example applications on this website, including an application that overlays a recording from a PC-video capture card with a StampPlot Pro screen. Although the system described in this article has been developed for rocket applications, it is also suitable for other video/telemetry systems such as remote controlled aircraft including helicopters, cars, boats or other interesting development projects.

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Web links

[1] www.picaxe.co.uk

[2] www.selmaware.com

[3] www.elektor-electronics.co.uk

COMPONENTS LIST (transmitter)

Resistors
R1,R2,R3,R6,R11,R12,R13,R16,R17 = 10kΩ
R4,R5,R8 = 3kΩ3
R9 = 2kΩ2
R7,R10 = 12kΩ
R14 = 1kΩ preset
R15 = 220Ω

Capacitors
C1,C2,C5,C13,C18 = 22µF 16V radial
C3,C4,C6,C7-C12,C16,C17,C19 = 100nF
C14,C15 = 18pF

Semiconductors
D1,D2 = 11DQ03
IC1 = MAX761
IC2,IC4 = MAX883
IC3 = PICAXE-18X
IC5 = FX614
T1 = BC557
T2,T3 = BC547

Miscellaneous
K1,K2 = 2-way PCB terminal block (e.g. Phoenix Contact # 1725656)
K3 = 14-way boxheader
K4 = RCA connector
K5 = SMA connector
K6 = 9-way sub-D connector, female, PCB mount
L1 = 22 µH
MOD1 = AWM630-TX (Low Power Radio Solutions)
X1 = 3.579MHz (3.58MHz) quartz crystal
PCB, ref. 050238-1

(receiver)

Resistors
R1,R2,R5 = 10kΩ
R3,R4 = 100kΩ

Capacitors
C1 = 22µF 16V radial
C2,C3,C6,C7,C8,C11-C14,C16 = 100nF
C4,C5,C9,C15 = 10µF 16V radial
C10 = 470µF 16V radial

Semiconductors
D1 = 11DQ03
D2,D3 = 1N4148
IC1 = MAX883
IC2 = MAX232 (DIP case)
IC3 = FX614

Miscellaneous
K1 = 2-way PCB terminal block (e.g. Phoenix Contact 1725656)
K2,K9,K10 = RCA jack, PCB mount
K3 = SMA connector
K4 = 9-way sub-D connector, female, PCB mount
K5,K6,K8 = 2-way pinheader
K7 = 3-way pinheader
MOD1 = AWM634-RX (Low Power Radio Solutions)
X1 = 3.579MHz (3.58MHz) quartz crystal
PCB, ref. 050238-2