Weather satellite images -
from Heath Robinson to hi-tech

This article describes how you can build your own system for receiving APT (automatic picture transmission) weather satellite images, but first let me indulge in some 'waffle' and history.

> I have deliberately indented certain paragraphs throughout. This is so that those who don't *want* to know all the technical details can read through the article, skipping the indented sections, so as not to be bombarded with too much jargon.

Most of you will have seen weather satellite images during weather forecasts on the TV. Perhaps some of you have wondered how complex and costly the equipment is that generates these images. When the first satellites were launched in the 1960s (yes, it really is that long ago!) the equipment used to receive and process the signals was bulky and expensive; it needed a technically competent person to operate it and was beyond the reach of amateur enthusiasts.

Twenty or so years ago amateurs with the appropriate skills (most of the equipment was then d-i-y) could afford to set up a receiving station. Now all the 'technical stuff' can be done with a modern PC, and the total cost is quite modest.

All satellites orbit the earth, but for weather satellites there are two specific types of orbit. The first is the polar orbit, the second is the geosynchronous orbit. This article will concentrate on the former.

The polar orbiting satellites orbit in a fixed plane relative to the sun, at an altitude of typically 850km and take about 100 minutes (1.66 hours) to complete one orbit.

> During this time the Earth rotates $1.66 \div 24 \times 360 = 25$ degrees. If, on one particular orbit, it passed directly over Greenwich in London, the previous orbit would have passed over the same latitude at 25 degrees east, and on the next orbit it would pass at 25 degrees west. The satellite 'scans' the earth below it, creating an image (wider than 25 degrees on the ground) such that the area scanned on consecutive orbits overlap.

The geosynchronous orbit is where the satellite appears stationary above the equator (at any given longitude). Satellite TV (e.g. Sky) uses this arrangement.

> The polar orbiting satellites have the ability to provide more detailed images, especially nearer the poles where the surface of the earth is 'falling away' from a geosynchronous satellite. The disadvantage is that the satellite is a 'moving target' and, for the best reception, this means the aerial must track the satellite's position.

Some history

I can't remember the exact year that I was first introduced to the thrill of receiving my very own weather satellite pictures, but it was a few years *prior* to the formation of RIG, the Remote Imaging Group, in 1985.

> The Remote Imaging Group (http://www.rig.org.uk/) was started by enthusiasts, but sadly, owing to some influential members leaving the group, it is not as active as it used to be. There has not been a 'regular' printed bulletin for some time, and the website hasn't been updated this year (2007).

> A relatively new group, GEO (Group for Earth Observation) http://www.geo-web.org.uk/ may prove to be a better option should you wish to become involved in the hobby.

David Duff, a radio amateur and very good friend, was the physics teacher at a secondary school in Lancashire. One Sunday, I was invited over and, together with a handful of enthusiastic pupils, we set about receiving a weather satellite signal. In those days, the BBC computer was used to predict when the satellite(s) could be 'heard'. The aerial we used was a homemade helix.

You're probably familiar with the yagi aerial design: just look at any standard TV aerial. The helix is a different kettle of fish. It is essentially a spiral, of the appropriate dimensions (diameter and length). Its advantage for weather satellite reception is that, whereas a standard yagi aerial is designed to receive horizontally or vertically polarised signals, the helix is designed for circularly polarised signals. And guess what? The satellites transmit a circularly polarised signal. There are two variants, left-hand and right-hand, so of course it's essential to obtain (or build) the correct one. See: http://en.wikipedia.org/wiki/Helical_antenna

The 137MHz receiver that we used was homemade by David. I can't remember now whether the audio signal from the receiver was recorded onto a tape recorder or 'printed' live, but I suspect the latter. Recording the signal onto a tape recorder has drawbacks because the signal must be recorded very accurately. Any speed variation when recording and/or playing back will result in a 'wobbly' picture.

The radio frequency signal, on approximately 137MHz, is amplitude modulated FM. First a 2400Hz signal is generated. This is amplitude modulated such that the 'volume' of the 2400Hz determines whether the resulting image needs to be black, white, or somewhere inbetween.

(Note that these satellites don't transmit colour images. Any colour you see on a picture is 'false' colour generated by software).

Synchronising pulses are also added to the 'picture'.

This amplitude modulated tone is then used to frequency modulate the 137MHz carrier. Reception uses the reverse of this process, where the synchronising pulses and/or the 2400Hz can be used as a 'clock'.

This is what the waveform looks like. This is a 2.5 second (approximately) sample, each 'cycle' being 0.5 seconds. The individual waves cannot be seen at this resolution.

If you download the WAV file from http://www.g4iat.co.uk/lwt/wx you can listen to a 34 second recording. (Note – file size approx 0.75MB)

More detail, including explanation of synchronisation pulses, can be seen at http://en.wikipedia.org/wiki/Automatic_Picture_Transmission and http://personales.ya.com/metbee/apt_format.html

Here is a small section of the 'raw' image that I received on 20th August 2007 at 17:17 GMT.
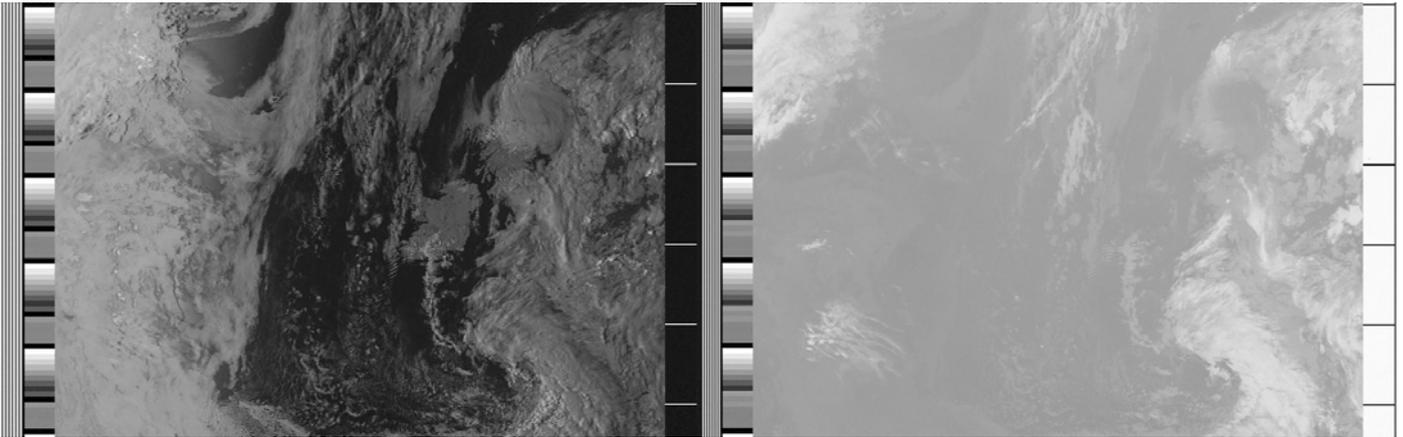
The left-hand image is visible light, the right-hand one infrared. The images are separated by the synchronisation pulses. In the visible image, Ireland can be seen just to the right of centre. The rest of the UK is obscured by cloud. It is very difficult to make out any land mass in the infrared image. Later, we shall see what other images can be generated from these, using specially written software.

I get the picture!

These days, we take printing from a computer for granted. In the 1980s, we used a fax machine, but possibly not like one you've ever seen before. It was about half the size of an upright piano! Photographic paper was loaded onto a drum and the drum was rotated while a beam of light was modulated by the audio signal. The light source was moved on a lead-screw such that, for each rotation of the drum, the light moved down the paper by one pixel. (Pixel is a term that was not in common use, as far as I know, in the 1980s, but conveys the effect very well.)

At the end of the satellite pass, we had a complete picture, but before we could see it we had to take the drum with the photographic paper into a darkroom to develop it. The sight of the picture forming before our very eyes was something I'll never forget.

By today's standards, the procedure I've just described may seem very cumbersome, but you have to remember that this was many years before PCs became affordable and powerful enough to match the quality of the (black and white) photographs we were producing.

In the mid 1980s, it became possible to build a 'framestore' – an electronic decoder/display unit for the satellite signals. It was designed by a Yugoslavian radio amateur (callsign YU3UMV), and construction details were published in a German magazine (UKW Berichte) which, fortunately, also had an English edition (VHF Communications).

Extra help was provided in the form of articles published in the RIG journals.

The framestore consisted of a large number of analogue and digital integrated circuits, a few memory chips and lots of switches and wiring. The output fed a black and white monitor. Over the next few years, various upgrades were described which improved the performance of the equipment. I was one of several hundred people to build one of these decoders and have only very recently retired it in favour of the computer software approach to decoding and displaying images.

Here are a couple of pictures of the framestore that I built.

I like to think, certainly from the external view, that it was as well built as any professional unit. (Un)fortunately I didn't take any pictures of my prototype!

The receiver I am currently using was built by myself from a 'Cirkit' kit.

If you look at the picture above you can't actually see the receiver, but it is in the diecast aluminium box that occupies the left one-third of the whole unit. It is underneath the board with the reddish-brown connectors around the edge. You should get an idea from that, that the receiver is quite small.

As I am still using this section of the equipment I decided I was not brave enough to dismantle the unit to photograph the receiver board!

Let's get up to date

So, what does a modern receiving system consist of?

First, you need a good location. The top of a mountain is preferable to somewhere low down in a valley in order to receive a good signal from all directions.

Next comes the aerial which consists of stacked crossed dipoles – also known as a turnstile – made from aluminium tubing. It needs to be mounted as high as possible to get the best possible 'view' of the satellite.

This is a picture, taken from ground level, of my own aerial (with a Sky satellite dish in the foreground).

The box underneath the lower pair of dipoles contains a mast-head preamplifier. This is specifically designed for the 136–138MHz weather satellite band and boosts the signal and overcomes any loss in the connecting cable.

An alternative aerial is the mechanically more complex quadrifilar. Commercial versions tend to be made from stainless steel. For an example, see:

http://www.dartcom.co.uk/products/qfh_antenna/index.php

Both types of aerial can be either home-made or commercially produced. These aerials will work in a loft but, depending on your roof covering, you may lose a considerable amount of the signal.

Both of these aerials are omnidirectional, i.e. they do not need to be pointed at the satellite. The helix aerial, mentioned previously, *is* directional and you would need some mechanism to track the orbit of the satellite.

The signal from the aerial needs to be fed into a suitable receiver. Not only must it be able to receive the correct frequencies, but it should be very stable with respect to the specific frequencies in use (i.e no frequency drift) and have the correct bandwidth.

> Conventional VHF/FM broadcasts have a wide bandwidth. Medium wave and short wave AM broadcasts are narrow bandwidth. The satellite receiver needs to be designed to cope with a bandwidth somewhere inbetween. One of the reasons for this is that the 'transmitter' is moving and the transmission frequency is thus shifted owing to the doppler effect. The ideal bandwidth is about 50kHz. Any wider and the signal-to-noise ratio will not be good enough, any narrower and you will lose some of the data, resulting in less detail on the displayed images.

There are a number of general-purpose commercial sets (scanners) available, a small number of commercial weather satellite specific sets, and there are kits available if you feel competent enough to build your own. Very occasionally, you will see second-hand equipment for sale. My suggestion would be to buy a receiver that has been specially designed for weather satellites.

I have not been able to compare my Cirkit receiver with any other, but I would imagine a more up-to-date design may provide better results. In addition, modern specialist weather satellite receivers have the facility to be controlled by software. This is useful if two satellites are 'in view' at similar times (on different frequencies). In software you can select priorities for which satellite signal to decode and the software will control the receiver to listen to the appropriate frequency.

For these reasons, I am planning on purchasing a new receiver and am tempted by the R2ZX at: http://www.geo-web.org.uk/shop.html

Excluding the cost of a computer, which I'm assuming you already have, you should be able to purchase a modest system (aerial and receiver) for about £150 new or £100 second-hand. In order to get a significant improvement in performance, you would probably need to double those prices. The advantage of spending more, on better equipment, is that you are less likely to be disappointed with the results and more likely to re-sell the equipment for a decent price should you find that you no longer need it.

The output of the receiver is an audio signal which can be fed into the line input on a PC. This is where all the processing is performed.

I'm using a software package called WXtoImg, the name being derived from WX, a common(?) abbreviation for 'weather', and Img, an abbreviation for 'image'. The basic version is free and will run on several computer platforms – Windows, Linux and MacOS (but not RISC OS). It can be downloaded from http://www.wxtoimg.com/downloads/ and if you just want to experiment without purchasing any equipment, I would be happy to supply a suitable WAV file, but note that these tend to be between 10MB and 20MB, so perhaps the best option here would be to make one available for download from my website.

Upgrading from the free version to the standard or the professional edition of the software provides access to many more features. The upgrade costs are currently about £40 and £60 respectively. For this you receive an email with an upgrade key which unlocks the features greyed out (or not even visible) in the free version.

So how does it work?

First the software needs to be 'calibrated'. This may sound quite daunting, but the software is well written and so the procedure is actually very straightforward. The volume of the audio being fed into the sound card must be adjusted within certain limits, the location of the ground station must be entered (your latitude, longitude and elevation), a slant correction applied to a received image to make the image 'vertical', and the Kepler elements must be updated.

> The Kepler elements essentially define the 'where' and 'when' for a satellite and they allow you to predict *where* it will be at some specific time in the future (or *when* it will be at some specific location in the future). A good description can be found at the section on 'orbital elements' at: http://www.orbitresearch.co.uk/docs/equations.html Fortunately you don't need to understand what is written there to update your computer.

Updating the Kepler elements is very easy provided you have an internet connection, but you must register to access the data, which is provided by the US Department of Defense, but is downloaded from: http://www.space-track.org/

The software can then be instructed to 'do its stuff'. There are numerous options to select and, in my own configuration, this comprises the following steps:

1. Work out when the satellite(s) can be heard.

2. Automatically start to record the audio as a WAV file at the start of a 'pass' (i.e. when the satellite can be seen by the aerial) and stop recording at the end of a pass. Each pass lasts approximately 15 minutes.

3. Decode the WAV file and generate various black and white or colour images.

4. Overlay an outline of country borders and grid lines on the images (†and lakes, rivers, cities if these options are selected).

   In order to do this accurately, your PC's clock must be accurate to within 1 second (or preferably better). The satellites cover the ground at about 7.5km per second, so a two-second error in your PC's clock would mean that the overlay is in error by 15km. The overlay can be moved manually if it is incorrectly aligned, but this can become quite tedious if it needs to be done on every image.

5. †Change the projection from 'normal' to polar equal-area.

   For the 'normal' projection, the final image always has vertical sides, irrespective of the angle (relative to lines of longitude) of the path that the satellite follows.

6. †Create a composite image (if two or more suitable overlapping images are available).

7. Save the images, overlay maps and thumbnails.

8. And last, but by no means least, upload selected images, with thumbnails, to my website. The bottom of the web page shows a table of when the next satellite passes are due. Try it now!

http://www.g4iat.co.uk/wx/noaa/

Software 'glitches' permitting, all this can be done 24/7 without my intervention. (I have seen a small number of "Socket Error" messages when the software was uploading images to my website)

(†Note: some of the more advanced features listed here and marked † are not available in the free version of the software.)

A couple of additional features of the upgraded versions that I haven't played with yet are:

3D images (for which you need red/blue glasses, which are posted to you when you purchase the upgrade) and the ability to create animations from the static images.

A comprehensive (40-page) PDF describing all the features of the WXtoImg software is available at: http://www.wxtoimg.com/support/wxgui.pdf

For those of you whose first language isn't English, this is also available in Spanish, French, German, Polish and Japanese. I suspect that the software can be configured to operate in some (or all) of these languages, as there are files in the WXtoImg folder with the relevant filenames.

Earlier, you saw a small section of a raw, black and white, visible + infra-red image. Next we shall see the result of processing on the whole image.
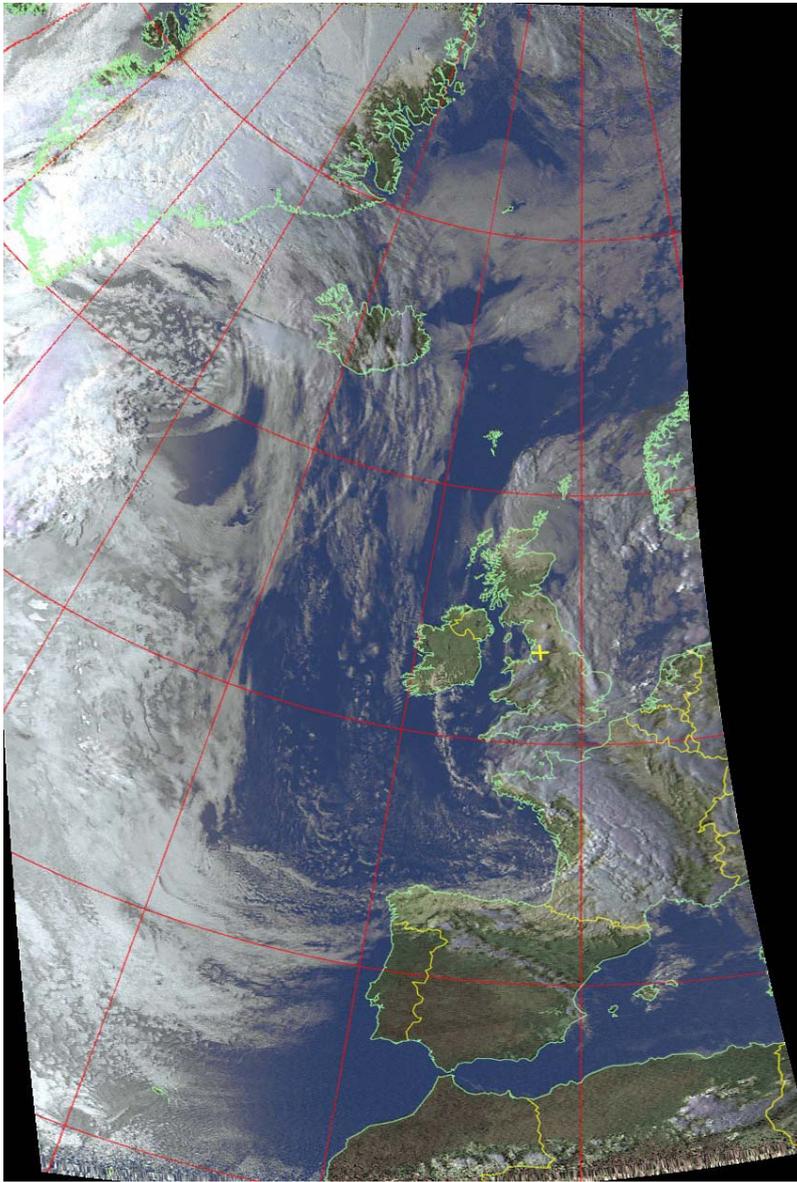
The visible and infrared 'grey-scale' images have been combined.

The synchronisation pulse 'strips' have been removed.

The image has been 'despeckled'. (This removes random noise which would otherwise show up as light or dark pixels)

An overlay has been created, showing country boundaries, latitude and longitude grid lines and a yellow '+' showing my location.

False colour has been added. (There are a large number of options available. This daylight-only option gives a pleasing result. For night-time satellite passes there is a false colour infra-red option).

The 'projection' has been changed from 'normal' to 'Lambert polar equal-area' (see explanation below).

Notice how the Greenwich meridian (0 degrees longitude) is vertical and the other lines of longitude converge towards the pole.

The 'normal' projection creates an image with vertical sides. It is essentially the view from the satellite as it passes over the earth in its inclined orbit. Owing to this inclination, the centre of the top of the picture will not be true (or magnetic, or grid) north. A typical image would have SSE at the bottom and NNW at the top when the satellite is travelling south to north, and NNE at the top, SSW at the bottom when travelling north to south.

A number of alternative projections are available, some of which you would find in an atlas. Probably the best known (by name) is the Mercator projection. Others include equidistant cylindrical, equal area cylindrical, polar stereographic and polar azimuthal equidistant.

Some of these projections create very unusual images so rather than try to describe them I have loaded small images onto a web page showing all the projections available. These have been created from a common 'normal' projection. See: http://www.g4iat.co.uk/lwt/wx2

Note – I have noticed that changing the projection from 'normal' to any of the other options is quite a processor-intensive operation, so a PC with a fairly fast processor is recommended if you plan to make extensive use of this feature. The WXtoImg website doesn't specify a minimum requirement, but I would suggest that any PC capable of running Windows XP should be more than adequate.

Below is a composite image made from three individual images, covering Greenland to Spain and mid-Atlantic to the Black Sea.

On the full-size image you can see that on the right-hand individual image the overlay does not exactly match the actual coastline. This was due to my PC clock being in error by a few seconds.
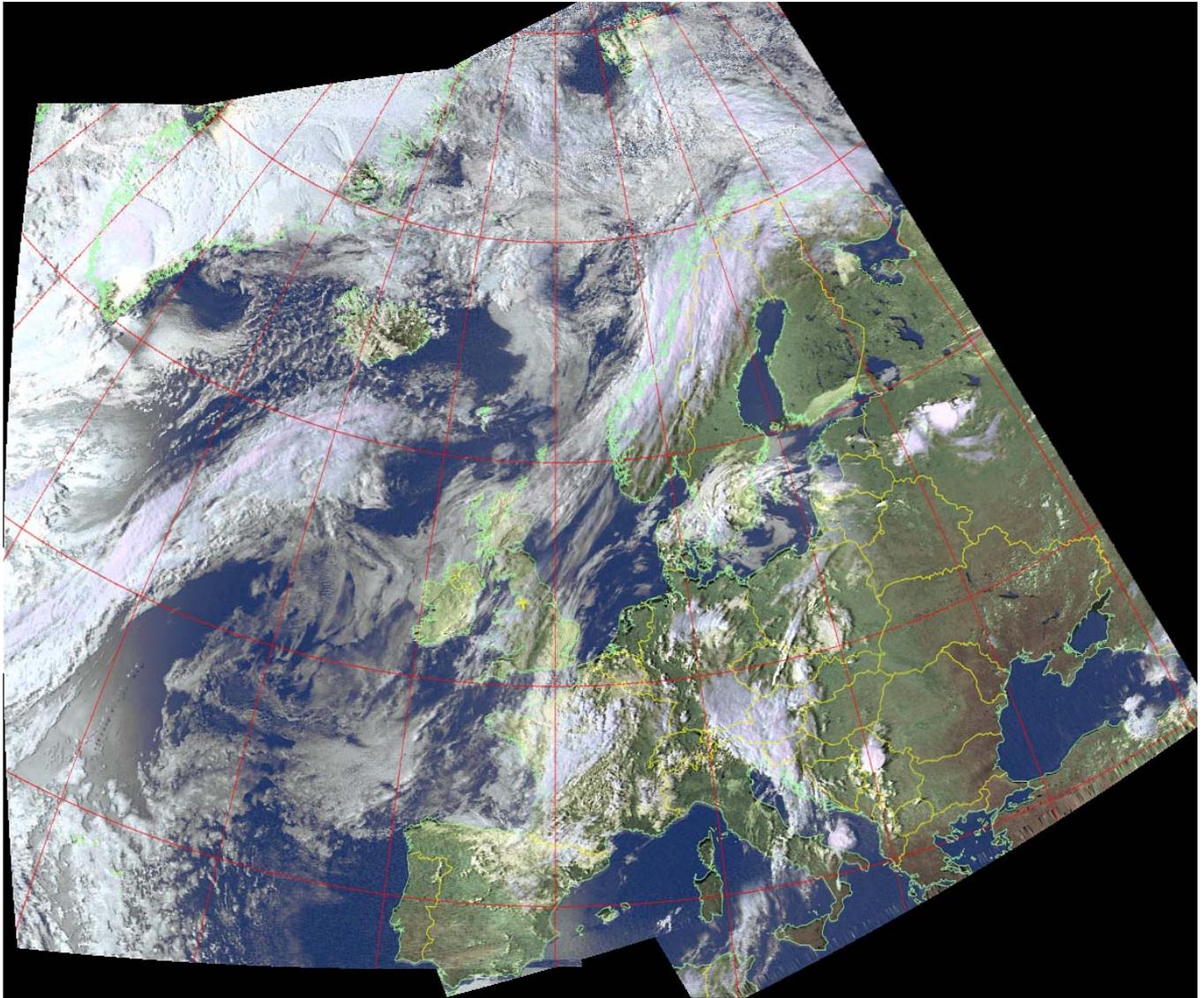
All the images used in this article can be downloaded from my website -
http://www.g4iat.co.uk/lwt/wx/

Finally, a few questions (and answers!) which didn't find their way into the main body of this article.

Does the satellite always pass over the UK at the same time and in the same direction?

Currently there are three active satellites I am receiving – NOAA15, NOAA17 and NOAA18, (NOAA being the American 'National Oceanic and Atmospheric Administration'). They are passing over the UK at various times of the day, south to north, and, approximately 12 hours later, north to south. As the satellites are 'staggered', this means that there is usually a satellite in range every couple of hours. It should also be noted that they transmit on different frequencies, so to record and decode the images automatically, there must be some circuitry, or software, to select which frequency to listen to.

Why does the PC's clock need to be so accurate and how do you achieve that?

The 'picture' you are receiving from the satellite is live. The Kepler elements define when it is passing over, say, the White Cliffs of Dover. The overlay is plotted based on this time. If your clock is two seconds fast and the satellite is travelling south to north, the overlay will be plotted two seconds earlier so that when you see the combined image and overlay, the coastline would appear to be in the middle of the English Channel!

Achieving and maintaining clock accuracy will be the subject of a (shorter!) follow-up article.

Why are the top and bottom of some images 'grainy'?

At the start of a pass, the satellite is only a few degrees above the horizon and is a long way away. If directly overhead, the satellite would be at a distance of approximately 850km. On the horizon it can be at a distance of more than 2500km. With a fixed, omni-directional aerial, even with a masthead preamplifier, there is not sufficient signal arriving at the receiver to create a noise-free image.

Sometimes the 'graininess', rather than being random, will have a pattern to it, often in the form of slanted horizontal bands. This is usually caused by interference from another radio signal and a common source is 'pager' transmitters which are on nearby frequencies.

At night, what do the visible images look like?

Dark! If there is insufficient daylight, the satellite automatically switches the normally daylight channel to another infra-red channel.

Can I get images with more detail?

Yes, but...! First, you have to consider the purpose of these satellites, and that is primarily to provide images for weather forecasters. They are interested in the clouds and weather patterns, not features on the ground. If you are interested in greater ground detail, there are better options – Google Maps and Google Earth.

The APT (automatic picture transmission) system that I have described is classed as LRIT – low-rate (or resolution) image transmission. HRIT (high-resolution) images are available from the same satellites but are transmitted on different (higher) frequencies and require a different receiver, a steerable aerial to track the satellite and different software to decode and display the signals.

Are there any other polar orbiting satellites in addition to the American NOAA series?

Yes, the Russians, Indians and Chinese have active satellites, but I don't currently have any details of their transmissions.

What about the geosynchronous satellites?

Up until the end of 2006, I was receiving images from Meteosat 7. The transmitted information was in a similar format to the NOAA, polar orbiting satellites and could be decoded and displayed by my YU3UMV framestore. We now have MSG – Meteosat Second Generation satellites. These transmit a digital signal and, initially, in addition to the extra difficulty of decoding the signal, a dish of 2.4m diameter was recommended in order to receive sufficient signal, so only amateurs with enough funds and space to install a dish of that size, were receiving images. Now a more modest (but still quite expensive) installation can be used because the signal is being re-transmitted on the Hotbird 6 satellite. See: http://www.time-step.com/products_msg.htm

Acknowledgements