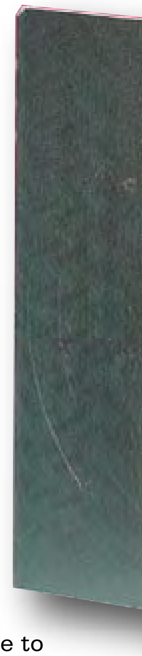
# WLAN Antenna Desi

## Increased range the easy way

Stefan Tauschek and Thomas Scherer

**The domestic use of WLANs has grown rapidly as DSL routers with built-in wireless Ethernet have become available, and now it is easy to use a notebook PC to surf the Internet wirelessly from the comfort of one’s sofa. However, things get trickier if a reinforced concrete wall stands in the way, or if a neighbour happens to be using the same frequency...**



The enormous popularity of WLANs (wireless local area networks) is easy to understand: not everyone has their desk situated next to a telephone socket. Even in the case of desktop PCs it is now easier to provide a fast Internet connection via the ether rather than by installing fixed cables. Unfortunately, things do not always go perfectly smoothly in practice: sometimes it can be difficult to set up a reliable connection between two devices even just a short distance apart in the same building.

## The problems and their causes

The frequency used for WLAN communications according to IEEE 802.11b or 802.11g is around 2.4 GHz. At this frequency radio waves propagate quasi-optically and are considerably attenuated by moisture in walls. Reinforced concrete and limestone block the waves to an even greater extent because of their high metal content. A further limitation is that in Europe transmit power in this band is limited to 100 mW.

Often also corners are cut in the interests of cost reductions. A WLAN router with a price tag of a few tens of pounds will make a few compromises in performance: a typical device will have inside a mini-PCI WLAN card, just as a laptop might. Such cards often only output around 50 mW rather than 100 mW, and poor matching to the antenna often accounts for a few more dB of loss. The overall effective transmit power might only be around 10 mW or 20 mW.

A straightforward way to recoup some of this loss is to use a special antenna that offers gain. And that is what this article is about: how to build a DIY directional WLAN antenna which focuses the available transmit power in the desired direction, providing a gain of several dB over a conventional omnidirectional antenna. Furthermore, a directional antenna does not just provide gain in the transmit path; signals received from sources within the antenna’s beam are amplified by the same factor. Since the WLAN connection is bidirectional, this means that a directional antenna can give us a considerable increase in range without the need for complex RF electronics.

## The solutions

When faced with a poorly-performing WLAN, it is wise to pause before reaching for the soldering iron. A couple of aspects should be considered before deciding to make or buy a directional antenna.
First it is worth noting that the best Ethernet connection is a wired one. A wired connection is both faster and more reliable. If this is not an option for any reason, or if (because connection is to be made to a notebook) it is not convenient, then there are a few things one can do to improve the performance of a wireless network. The first step is to try moving the router a few feet closer to the computer. Another option is to splash out a few tens of pounds on a repeater, which can add five to ten metres of range within a building. Even better is to deactivate the WLAN part of the router and, for a similar sum, purchase an access point (see **Figure 1**). This is a box of electronics which takes an Ethernet connection on one side and provides a WLAN connection on the other. The device can be connected to the router using an Ethernet cable. Because the device is dedicated to the one function, we might reasonably hope that it would provide better RF performance. A more significant advantage is that multifunction devices that combine a DSL modem with WLAN router and switch functions do not normally have a usable RF connector, and so it is hard to connect an external antenna. The small stub antenna usually provided is connected by a fixed wire to a sub-miniature connector on the internal WLAN card. This connector is not designed for repeated

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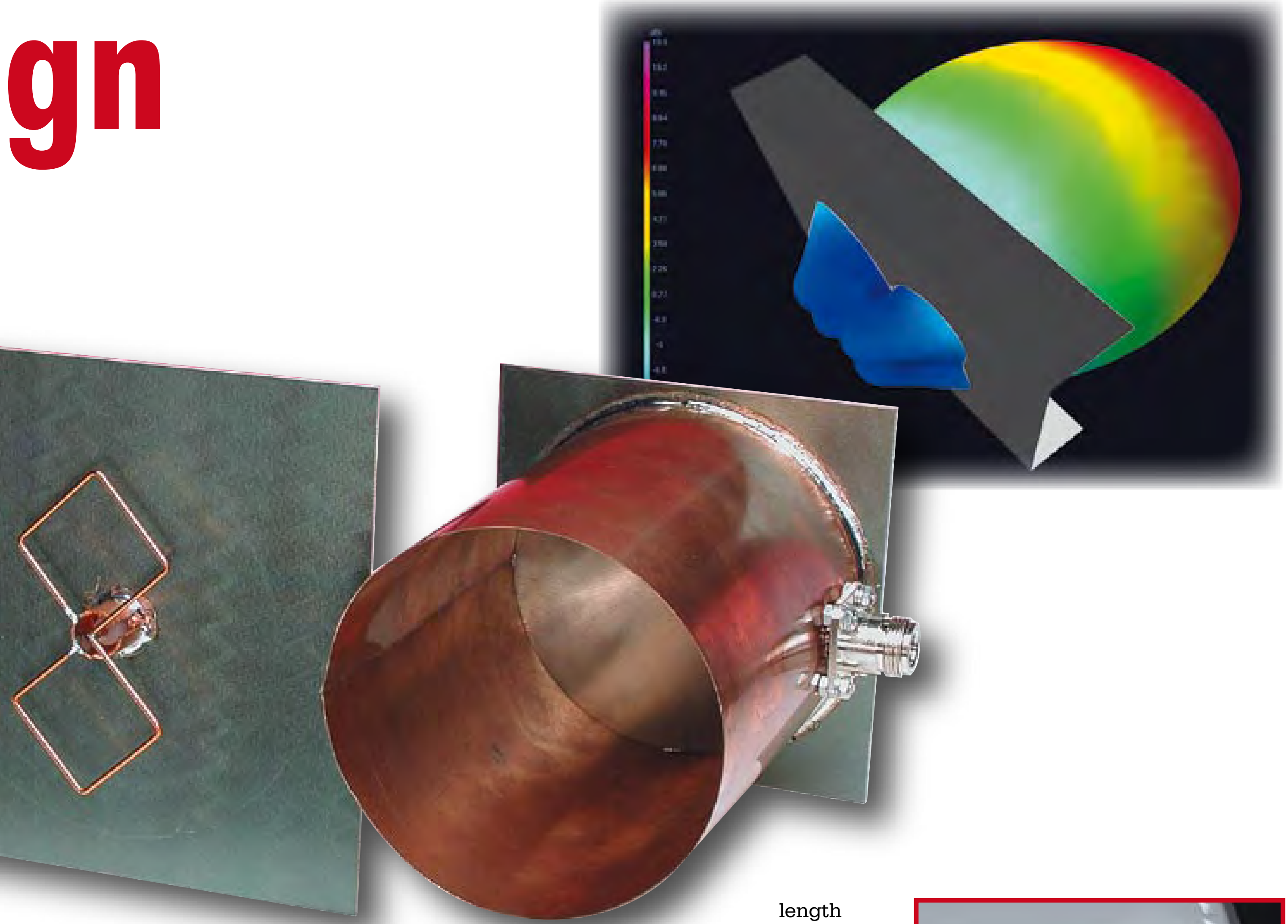


plugging and unplugging and is unmanageably tiny. Access points, however, are available with common-or-garden SMA connectors (see **Figure 2**), making it easy to connect an external purchased or home-made directional antenna.

One further piece of advice: it is preferable to use a longer Ethernet cable rather than a longer antenna cable. It is easy to achieve data transfer rates of 100 Mbit/s over 50 m or more of CAT5 cable; but the losses in 50 m of antenna cable could easily cancel out the benefits of a directional antenna.

## Antenna types

In the following discussion we shall not consider WLAN routers that employ several antennas and MIMO (multiple input multiple output) technology. Commercially-available access points (such as the one shown in Figure 1) are usually fitted with a so-called quarter-wavelength stub antenna, or monopole (see **Figure 3**). Sometimes the stub can be entirely inside the enclosure (as long as it is made of plastic). The antenna consists of a piece of wire with length $\lambda/4$. At 2.44 GHz, this is a quarter of $300\times10^6$ / $2.44\times10^9$ metres, or slightly more than 3 cm.

At the other end of the spectrum from this simple antenna is the parabolic reflector, which can have a diameter of several metres. This can offer a gain of up to 60 dB over the simple quarter-wavelength monopole. European regulations only allow such antennas to be fed at a very low power. Experiments in the USA with specially-constructed (and expensive) antennas of this type have achieved ranges of up to 200 km.

A wide range of directional antenna designs between these two extremes have been tried for WLAN applications. Two designs have proved most successful, offering good gain and simple construction. The first type takes the form of a waveguide and goes by the catchy name of ‘cantenna’ (see left-hand half of **Figure 4**). The second type consists of specially-arranged diamond-shaped sections in front of a reflector, and is called a ‘biquad’ (see right-hand half of Figure 4). The lat-

Figure 1. SMA connector on the rear panel of an access point.

Figure 2. A typical access point: sometimes these are used to help reduce the length of antenna cable needed.

Figure 3. **Quarter-wavelength stub antenna suitable for a WLAN router or access point.**

Figure 4. **Prototype cantenna and biquad antenna constructed in the Elektor Electronics laboratory.**

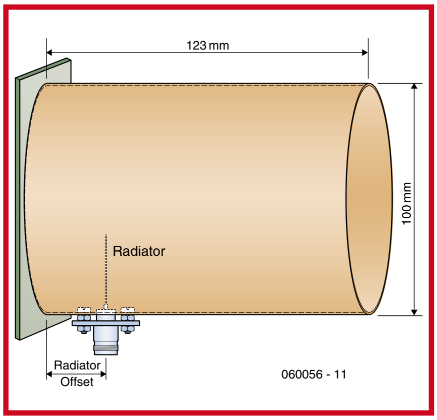


Figure 5. **Construction drawing for the cantenna.**

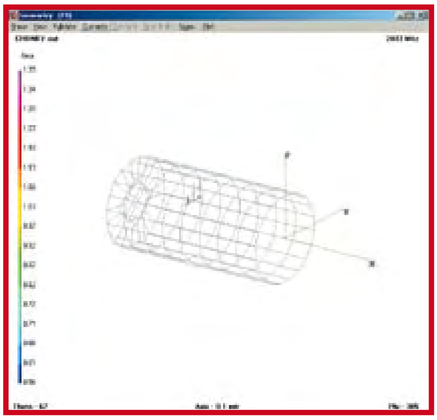


Figure 6. **Three-dimensional model of the cantenna plotted by 4NEC2.**

ter type can in theory offer a gain of around 12 dB (although as we shall see later, practice can deviate from theory!), somewhat more than the 10 dB that the cantenna can provide. Both types give considerable improvements over typical integrated antennas, and we shall now go on to look at them both in more detail.

## The cantenna

As mentioned above, the cantenna operates as a kind of waveguide. The theory of such antennas is far from trivial; those interested can find a good introduction at [1]. As can be seen from Figure 4 and the drawing in **Figure 5**, the antenna consists of a can of certain specified dimensions and a carefully-arranged feed.

There is a wide range of guides available to constructing cantennas of various dimensions [2]. The following suggestions have the advantage that they have been tested by simulation, carried out by Stefan Tauschek using a software package called 4NEC2, available for free download from [3]. The program is based on the so-called boundary element method [4]: the idea is to convert Maxwell's equations into a system of linear algebraic equations, which are then stepwise integrated to calculate the current distribution in the antenna. The 'NEC' in the program name stands for 'numerical electromagnetic code'. Although their derivation is complicated, the results themselves are simple: **Figure 6** shows the three-dimensional model of the Cantenna in 4NEC2 and **Figure 7** the calculated radiation pattern. The directional nature of the antenna is clear.

To make an accurate cantenna the can must be exactly one wavelength long. At 2.44 GHz this is very nearly 123 mm. The internal diameter is approximately 100 mm, slightly more than 4/5 λ.
The feed stub, shown as a radiator, should be approximately λ/5, or 25 mm, long. Ideally this is a wedge-shaped or tapered piece of metal, with the thicker end pointing to the middle of the can. The distance from the base of the can, the 'radiator offset', is the rather odd multiple of 7/32 times the wavelength, or 27 mm.

It is difficult to find ready-made cans with these dimensions. A reasonably accurate version can be made by hand from copper sheet as shown in Figure 4; deviations of up to 10 % from the nominal dimensions should be tolerable for ordinary use. Of course, there is plenty of scope for experimentation.
The trickiest part of construction is connecting to the radiator. We can start from a commercially-available N-type RF connector. **Figure 8** shows an example of this type of connector with a radiator (sometimes called 'exciter') soldered to it. A suitable hole must be made in the can to fit the connector. Washers should be used when fitting the connector to avoid damage to the can. The antenna is now ready for use. If it is to be used outside it is worth considering waterproofing the connection to the radiator.
Adaptor cables from N-type connectors to SMA connectors or other types are available ready made; alternatively, it is easy, as well as cheaper, to make up a suitable cable oneself. As noted above, the antenna cable should be no

## In the Elektor

When we had constructed prototypes in our laboratory we naturally wanted to test them immediately. The test equipment comprised an ordinary laptop and a PC as the fixed station to which the various antennas were connected. The walls of the laboratory building are built using a type of brick that absorbs RF of this frequency very well. The layout of the building is a chain of rooms in a slightly staggered arrangement. There are many PCs and other electronic devices in the laboratory and in the editorial offices, producing a high level of electromagnetic interference.

We tested the ranges of four antennas: an ordinary λ/4 stub, the biquad, the cantenna, and a commercial model (the HA-O14SD from Hawking Technology: see ***Figure 12***) costing around fifty pounds, with a quoted gain of at least 14 dB. In each case the antenna was connected to the WLAN card in the

## Web links

**[1] Waveguide theory:**
http://en.wikipedia.org/wiki/Waveguide_%28electromagnetism%29

**[2] Various antenna designs:**
http://qdg.sorbs.net/qdgant.htm

PC using an RF cable three metres long.

We achieved the following results:

| | |
|---|---|
| 1) Stub: | 10 m |
| 2) HAO14SD: | 20 m |
| 3) Biquad: | 21 m |
| 4) Cantenna: | 26 m |

Here again the cantenna comes out on top. The performance of the commercial antenna teaches us two things: first, one should not always believe in a manufacturer's sometimes rather optimistic gain figures (the antenna is delivering an estimated gain of around 6 dB rather than 14 dB); and second, the DIY approach often pays off!

**Figure 12.** The commercial directional WLAN antenna used for comparison tests.

longer than necessary in order to get the most benefit from the gain of the antenna.

## Biquad

An alternative design of antenna, which is also easy to construct, is the biquad. This takes the form of an angular figure-of-eight pattern of wire in front of and parallel to a reflector surface. The design has proved very popular on the Internet, where there are countless construction guides, no doubt because of its good theoretical performance and 'high-tech' appearance. The design described here has the advantage, shared with the cantenna above, that it has been simulated and optimised by computer.

In essence the biquad is a folded multiple $\lambda/4$ dipole. As **Figure 9** shows, the resulting shape resembles a figure-of-eight. Each edge of the two squares is $\lambda/4$ = 30.5 mm long. A suitable material is 1 mm copper wire. The feed connection is made between the point where the two squares meet and the open ends, which are connected to ground (the feed cable screen). **Figure 10** clearly shows the current distribution due to the individual antenna elements. Current nodes and antinodes can be seen at the corners of the square: the antenna is in resonance.

The figure-of-eight should be mounted approximately 15 mm to 17 mm in front of the reflector. Practical experiments have shown that it is possible to achieve an excellent SWR (standing-wave ratio) of 1:1.15.

It is recommended that the side of the reflector should be equal to one wavelength. In other words, the ideal reflector is a conducting square of metal measuring 123 mm on each side. Various materials are suitable: in the prototype we found copper-clad printed circuit board satisfactory. A reflector could also be made from a CD (the metallised part has diameter approximately 118 mm). The dimensions of the multi-dipole are unfortunately rather critical.

As shown in Figure 4, a suitable piece of copper pipe can be used to fix the biquad figure-of-eight. The pipe is soldered to the reflector and the RF coaxial cable passed through the pipe as the feed. The central conductor of the cable is then directly soldered to the middle of the figure-of-eight. Alternatively, an N-type connector can be used as with the cantenna, the correct distance to the reflector being achieved using two pieces of copper wire of suitable length.

The figure at the beginning of the article shows the radiation pattern of a biquad antenna whose reflector is fitted with two plates, 30 mm high, on opposite sides to attenuate the rearwards-pointing lobes. Using this construction a gain of between 10 dB and 12 dB can be achieved. There are reports of laptops equipped with biquad antennas connecting to an access point (also with a specially-constructed antenna) 10 km away.

## Miscellanea

Tall tales of spectacular results obtained by avid WLAN hunters abound, but it is true to say that there can be enormous differences in practically-achievable range depending on the local townscape or countryside, on

**[3] 4NEC2 software:**
http://home.ict.nl/~arivoors

**[4] Boundary element method:**
http://en.wikipedia.org/wiki/Boundary_element_method

**[5] Download page for NetStumbler:**
http://www.netstumbler.com/downloads

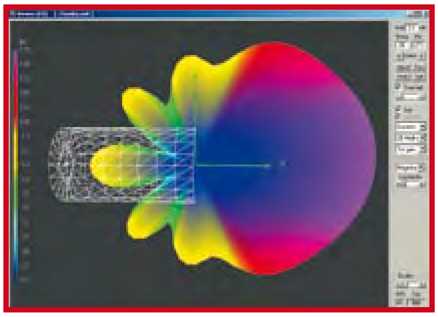


**Figure 7.** Radiation pattern of the cantenna calculated using 4NEC2.

**Figure 8.** N-type connector with a tapered radiator made from copper sheet soldered to it.

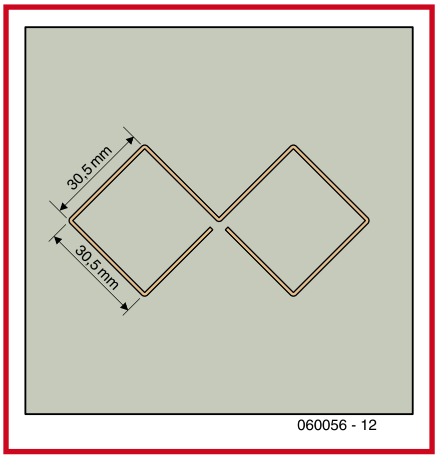


**Figure 9.** Construction drawing for the figure-of-eight biquad antenna.

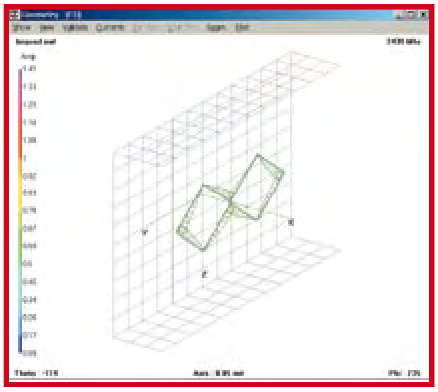
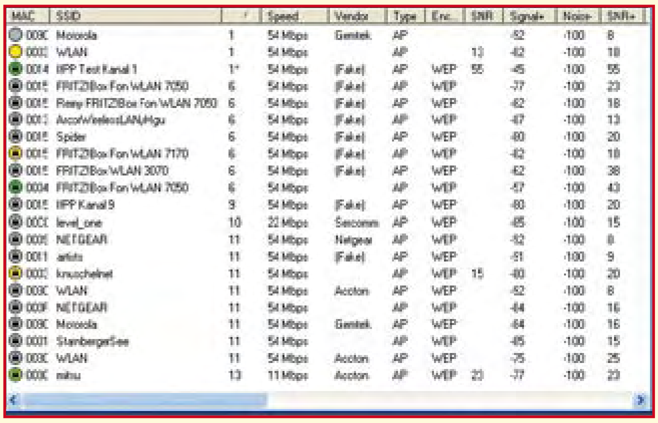


**Figure 10.** Current distribution for the biquad antenna calculated using 4NEC2.

## Antennas in practice

The most detailed calculations and highest technical specifications count for nothing if good results are not achieved in practice. We therefore decided to take the antennas we built in the Elektor Electronics laboratory according to the designs calculated by Stefan Tauschek for a practical test. The most stringent test involved installing the various antennas at the home of Thomas Scherer in Frankfurt city centre and then using an ordinary Centrino laptop running NetStumbler to measure the signal strength in the street outside and determine over what range a connection could be achieved.



| MAC | SSID | Chan | Speed | Vendor | Type | Enc. | SNR | Signal+ | Noise- | SNR+ |
|---|---|---|---|---|---|---|---|---|---|---|
| 003C | Motorola | 1 | 54 Mbps | Gemtek | AP | | | -52 | -100 | 8 |
| 000 | WLAN | 1 | 54 Mbps | | AP | | 13 | -42 | -100 | 18 |
| 0014 | IfPP Test Kanal 1 | 1* | 54 Mbps | (Fake) | AP | WEP | 55 | -45 | -100 | 55 |
| 0015 | FRITZ!Box Fon WLAN 7050 | 6 | 54 Mbps | (Fake) | AP | WEP | | -77 | -100 | 23 |
| 0015 | Remy FRITZ!Box Fon WLAN 7050 | 6 | 54 Mbps | (Fake) | AP | WEP | | -62 | -100 | 18 |
| 0013 | AccoWirelessLAN/Hgu | 6 | 54 Mbps | (Fake) | AP | WEP | | -47 | -100 | 13 |
| 0015 | Spider | 6 | 54 Mbps | (Fake) | AP | WEP | | -80 | -100 | 20 |
| 0015 | FRITZ!Box Fon WLAN 7170 | 6 | 54 Mbps | (Fake) | AP | WEP | | -42 | -100 | 18 |
| 0015 | FRITZ!Box WLAN 3070 | 6 | 54 Mbps | (Fake) | AP | WEP | | -62 | -100 | 38 |
| 0004 | FRITZ!Box Fon WLAN 7050 | 6 | 54 Mbps | | AP | WEP | | -47 | -100 | 43 |
| 0015 | IfPP Kanal 9 | 9 | 54 Mbps | (Fake) | AP | WEP | | -80 | -100 | 20 |
| 000C | level_one | 10 | 22 Mbps | Senao | AP | WEP | | -85 | -100 | 15 |
| 0009 | NETGEAR | 11 | 54 Mbps | Netgear | AP | WEP | | -82 | -100 | 8 |
| 0011 | artists | 11 | 54 Mbps | (Fake) | AP | WEP | | -51 | -100 | 9 |
| 000 | knuschelnet | 11 | 54 Mbps | | AP | WEP | 15 | -80 | -100 | 20 |
| 003C | WLAN | 11 | 54 Mbps | Accton | AP | WEP | | -82 | -100 | 8 |
| 000F | NETGEAR | 11 | 54 Mbps | | AP | WEP | | -84 | -100 | 16 |
| 003C | Motorola | 11 | 54 Mbps | Gemtek | AP | WEP | | -84 | -100 | 16 |
| 0001 | StarnbergerSee | 11 | 54 Mbps | | AP | WEP | | -85 | -100 | 15 |
| 003C | WLAN | 11 | 54 Mbps | Accton | AP | WEP | | -75 | -100 | 25 |
| 003C | mitsu | 13 | 11 Mbps | Accton | AP | WEP | 23 | -77 | -100 | 23 |

**Figure 11. List of WLANs found by NetStumbler.**

The screendump in ***Figure 11*** was taken immediately outside the building. It shows that in this are there are many WLANs competing for the airwaves. The strongest signal, with SSID 'IfPP Test Kanal 1', is being produced by the access point shown in Figure 2 set up for this test.

**Table 1. Typical antenna ranges in the city centre.**

| | Antenna type | | |
|---|---|---|---|
| **Distance** | **Stub** | **Biquad** | **Cantenna** |
| 20 m | –84 dB | –80 dB | –72 dB |
| 30 m | – | –85 dB | –80 dB |
| 40 m | – | – | –86 dB |

The building is a five-storey reinforced concrete structure built in the 1980s. The walls screen radio signals so effectively that radio and digital television reception is difficult, even though the transmitter is only 4 km away. The WLAN router is situated in a hallway on the third floor, surrounded by walls. Even just 5 m away, on the floor above, signal quality has dropped from 'excellent' to merely 'good'. Inside the building only four of the 21 WLANs shown in Figure 11 can be received. The building thus makes an excellent test location..

Table 1 shows how far the radio waves propagate along the street outside the building, after attenuation by one wall. The directional antennas were, of course, correctly aligned for the test. The first surprise is that the biquad is clearly outperformed by the cantenna. The reason for this disagreement with the theoretical results was not found: cable connections and the like were thoroughly checked. In the city (and with one wall interposed between transmitter and receiver) the cantenna offers approximately double the range of the ordinary stub antenna. The performance of the biquad antenna sits between the two: we eagerly await the comments of our expert readership in the Elektor Electronics online forum!

To see what a directional antenna is capable of, we need to get away from the electromagnetic smog of the city. To this end we moved the test setup to a house on the outskirts of a small village. The antenna, connected to an access point, was arranged to transmit from the (open) front door of the house over the fields beyond. The measurements therefore give the line-of-sight performance of the antennas. Besides the test WLAN, NetStumbler found two other WLANs in range, but both were at least six channels away from the test frequency.

**Table 2. Ranges achieved in open countryside.**

| | Antenna type | | |
|---|---|---|---|
| **Distance** | **Stub** | **Biquad** | **Cantenna** |
| 40m | 22 Mbit | 48 Mbit | 54 Mbit |
| 60m | – | 11 Mbit | 54 Mbit |
| 120m | – | – | 5,5 Mbit |

Table 2 shows that line-of-sight communication is possible over considerably greater distances than in the city. We have shown the communication rates achieved, as this is the most practically useful figure. Communication over 120 m using a tin can is not a bad achievement, we think! The tripling of range achieved using the cantenna, compared to the stub antenna, is in line with the theoretical gain figure of 10 dB.

If both access point and laptop are equipped with directional antennas, ranges under these conditions of over 200 m can easily be obtained. In this case the laptop must be used in conjunction with an external WLAN adapter (either a PCMCIA card or connected via USB) which has an RF connector, although this arrangement does make the laptop rather unwieldy!

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house layout and construction material, and even on the neighbours! For example, in Frankfurt city centre where Thomas Scherer carried out his antenna field tests there is practically no point where a laptop cannot pick up signals from at least 15 WLANs, and the same would go for any other major European city. To this we can add interference from microwave ovens, mobile telephones and other transmitters, all in or near the frequency band we are interested in. Things are quieter (as yet) in the 5 GHz band used by IEEE 802.11a WLANs. It is also worth noting that the channels available in Europe, numbered from 1 to 13 in the IEEE 802.11b and 802.11g standards, provide for only three non-overlapping channels. A powerful WLAN run by a neighbour can interfere with between three and six channels on either side.

If problems with signal quality are encountered, the first thing to check is what transmitters are active in the neighbourhood. The NetStumbler program [5], a favourite of 'wardrivers' (people who drive around looking for WLANs using a laptop) is helpful here. It scans the radio frequencies in a configurable fashion and shows information about the various networks available, including their SSIDs and signal strengths. Depending on the WLAN hardware, the results might not always be perfectly accurate, but the relative values do usually give a good overview of the situation.

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