Investigation of 433MHz Tx/Rx pairs

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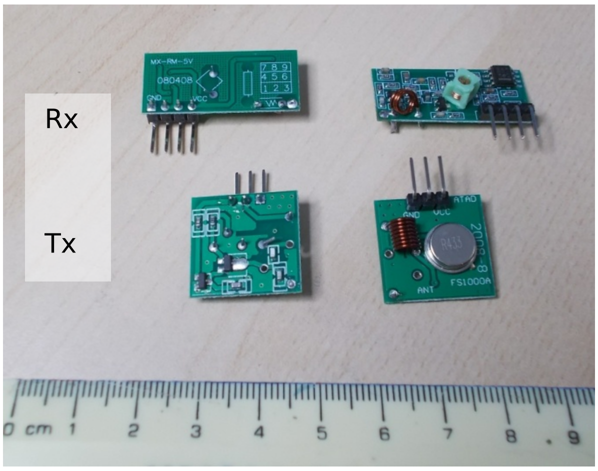
Recently I've been looking at simple wireless datacomms to a host computer using the 433MHz licence-exempt band. Currently there are multiple suppliers of a transmitter/receiver pair, Chinese made, which are extremely cheap – the typical price being no more than £2 a set. Of course, the specification at such a price is not just equally low, more often than not it's completely lacking. So I thought I'd order a few and subject them to a somewhat more rigorous review than you can get by looking at the sales info. This article is the result.

The units look like this:



They're intended to be used for low data-rate amplitude-shift keying (ASK, or on-off transmission) applications. The 433MHz band is very widely used for this kind of thing, typically garage door openers and other home automation purposes. Because it's so popular, it's vital to transmit a coded signal which would only be recognised by the intended receiver, and would be ignored by all other receivers in the neighbourhood – the extent of the neighbourhood being, potentially, several tens of metres. Conversely, your receiver must expect to operate in such an environment and so your software has to be capable of correctly decoding a wanted transmission without being affected by interference or by any others.

This article only looks at the RF specifications of the units under investigation and doesn't do more than touch on the software aspects of the transmission or reception. A full evaluation of their use in a system would need to consider the relationship between bit-error-rate (BER) and sensitivity and is well beyond the scope of this piece.[1]

[1] See e.g. Texas Instruments, *System Design Considerations Using the TRF1400/TRF1401 RF Telemetry Receivers*, Application Report SLWA005B APRIL 1997

The licence-free requirements

In the UK, devices like this are regulated under the Short Range Devices licence exemption. The relevant document is Ofcom's IR2030, which has a table showing the requirements and limitations under which they can operate. For a hobby-type application with these simple units the category of interest is "Non-specific short-range devices" under IR2030/1/10 and /11. The specifications are:

Frequency range: 433.05 - 434.79 MHz (±870kHz around 433.92MHz)

Maximum transmit power: 10mW erp with a duty cycle limit ≤10% (/1/10)
1mW erp with no duty cycle limit (/1/11)

Reference standard: EN 300 220-1 (a European standard which contains much more technical detail)

A principal question then is whether the units do actually comply with these requirements so that a naive user can add them to their system without fear of infringing the regulation.

The specification

Some of the sellers do quote a semi-specification which seems to apply across the board to this design, so I have used this as a starting point. Here it is, in all its glory:

Receiver module parameters
1.Product Model: MX-05V
2.Operating voltage: DC5V
3.Quiescent Current: 4mA
4.Receiving frequency: 433.92MHZ
5.Receiver sensitivity:-105DB
*6.Size: 30 * 14 * 7mm* *[2]
7.External antenna: 32CM single core wire, wound into a spiral

Technical parameters of the transmitter head
1.Product Model: MX-FS-03V
2.Launch distance :20-200 meters (different voltage, different results)
3.Operating voltage :3.5-12V
*4.Dimensions: 19 * 19mm* *
5.Operating mode: AM
6.Transfer rate: 4KB / S
7.Transmitting power: 10mW
8.Transmitting frequency: 433M
9.An external antenna: 25cm ordinary multi-core or single-core line
10.Pinout from left → right: (DATA; VCC; GND)

So with four pairs to play with let's see how these stack up, looking at the transmitter first.

[2] The dimensions, for what it's worth, only apply to the PCB and don't include the connector pins

The transmitter

It's relatively straightforward to make measurements on the transmitter output directly, rather than on an external antenna. These measurements were made with a Rigol DSA832E spectrum analyser coupled to the output pad via a short cable and a 10dB attenuator pad, both to protect the analyser and to ensure a close 50Ω match, as is the standard for RF measurements. This means that the output power can be directly quoted in dBm, once the analyser's reading is corrected for the cable loss and 10dB attenuation.

The DATA input pin (rather quaintly marked as "ATAD" on the silkscreen) was held high at the same voltage as the supply, except for the rise/fall time measurement where it was pulsed with a 600µs single pulse. The transmitter was therefore operating continuously, which is perhaps an unfair test as it would normally be pulsed on/off with the data bits and at a low duty cycle. At the higher voltages it did get warm, but survived.

The design of the transmitter is minimalist. It's based around a metal can component marked "R433" which I assume to be a SAW resonator, perhaps an equivalent to the earlier EPCOS B39421-R2531 types. Two SOT23 transistors and a handful of passive components create a keyed oscillator and power driver – and that's it. From the marking on the transistors, one is a 2SC3838Q (200mW, V_{CEO} 11V, F_T 3GHz) while the other is a general-purpose switching transistor used to buffer the data input.

The tables below summarize the measurement results, divided into those parameters that were largely constant between the four units, and those that showed a spread. Since the available specification quoted a supply voltage range of 3 – 12V, voltages of 3, 5, 8 and 12V were tested; it was also found that the devices would operate down to less than 1.5V, so this was tested as was the voltage below which operation ceased completely (the dropout voltage).

Table 1. Common parameters

Data input impedance	10 kΩ + V_{BE}	
Rise time @ 5V	14	µs
Fall time @ 5V	25	µs
Quiescent current (DATA = 0V)	<1	µA
Dropout voltage	1.2	V

The four units are separately identified below by colour coding.

Table 2. Frequency

Unit	V_{CC}	1.5	3.0	5.0	8.0	12.0
Orange*	Initial freq MHz	433.84	433.8405	433.842	433.845	433.843
	Freq drift @ 3mins	0.000%	0.001%	0.002%	0.005%	-0.005%
Yellow	Initial freq MHz	434.027	434.027	434.028	434.023	433.97
	Freq drift @ 3mins	-0.001%	0.000%	0.000%	-0.005%	-0.022%
Blue	Initial freq MHz	434.0216	434.0216	434.0216	434.016	433.98
	Freq drift @ 3mins	0.000%	0.000%	0.000%	-0.004%	-0.022%
Pink	Initial freq MHz	434.035	434.038	434.04	434.03	433.97
	Freq drift @ 3mins	0.000%	0.000%	-0.001%	-0.006%	-0.032%

Table 3. Output power (continuous: 0dBm = 1mW, power in mW = $10^{[dBm/10]}$)

Unit	V_{CC}	1.5	3.0	5.0	8.0	12.0
Orange*	O/p power dBm	-15.2	-3.72	1.8	6.06	10.8
	dB drift @ 3mins	0.00	0.09	0.22	0.22	-0.50
Yellow	O/p power dBm	-9.7	0.5	4.97	8.4	12.7
	dB drift @ 3mins	-0.10	-0.20	-0.13	-0.10	-1.00
Blue	O/p power dBm	-9.6	0.1	4.93	8.65	13.09
	dB drift @ 3mins	-0.10	0.20	0.04	0.09	-1.89
Pink	O/p power dBm	-9.2	0.22	4.74	8.34	13.33
	dB drift @ 3mins	0.05	0.02	0.02	-0.02	-0.29

Table 4. Supply current and efficiency

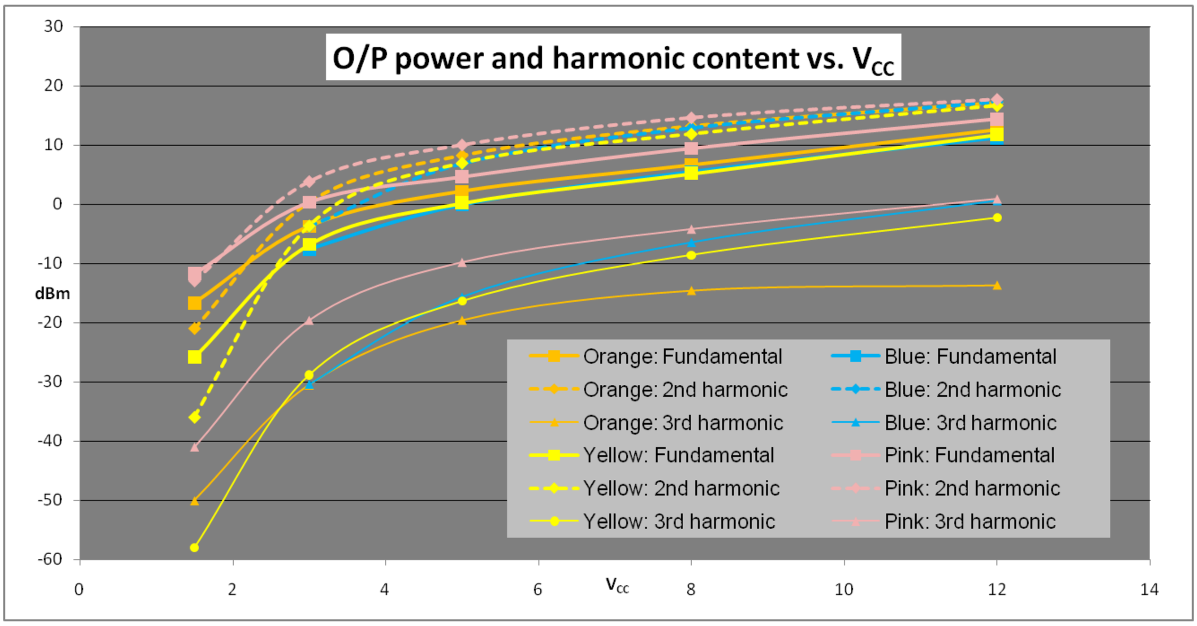
Unit	V_{CC}	1.5	3.0	5.0	8.0	12.0
Orange*	I_{CC} mA	2.33	8.54	17.2	30	55.9
	% change @ 3mins	0.43%	0.47%	0.99%	2.33%	-1.07%
	Power efficiency	0.86%	1.66%	1.76%	1.68%	1.79%
Yellow	I_{CC} mA	3.24	10.4	18.26	30.24	57.9
	% change @ 3mins	-0.31%	0.58%	1.10%	3.51%	-4.49%
	Power efficiency	2.20%	3.60%	3.44%	2.86%	2.68%
Blue	I_{CC} mA	3.12	9.82	17.17	27.8	49.5
	% change @ 3mins	0.00%	0.20%	0.76%	1.51%	-9.49%
	Power efficiency	2.34%	3.47%	3.62%	3.30%	3.43%
Pink	I_{CC} mA	3.45	10.27	18.1	29.8	65
	% change @ 3mins	0.00%	0.39%	0.72%	2.48%	-2.31%
	Power efficiency	2.32%	3.41%	3.29%	2.86%	2.76%

* post burn-in

The power efficiency (power out divided by power in) as shown above is not great, and is best in the region of 3–5V V_{CC}. In these tests, the “orange” unit is noticeably different from the others; it may have been stressed more than the others, being the first under test. The other three have similar levels of output power at the different supply voltages, although see below regarding “burn-in” observation.

The amplitude of spurious emissions is important for a complete understanding of the device. In this case, since the device oscillates at the transmission frequency, there are no spurious emissions except at multiples (harmonics) of this frequency. The fundamental, second harmonic (868MHz) and third (1302MHz) are shown versus power supply voltage in the graph in Figure 1. Notice that the second harmonic (the dashed line) is actually greater than the fundamental (intended) transmission at most voltages for all units. The blue unit, on this test, couldn’t be measured at 1.5V as it wouldn’t start.

Figure 1. Output power and harmonic content versus supply voltage



Observations

2nd harmonic emissions

The most significant property of these units is their higher level of emission at 868MHz, by a typical factor of 4-6dB (6dB is four times power), compared to the intended transmission. Any user who can't check the operation with a spectrum analyser would be quite unaware of this. As it happens, the 868MHz band is also a licence-exempt band for short-range devices[3]; higher power levels are also permitted, albeit with stricter limits on duty cycle. So in fact, you're getting a two-in-one solution. If it doesn't work or is unreliable at 433-434MHz, try receiving at 868MHz and you may well be lucky. (I'm not suggesting this as an initial design choice!)

However, EN300 220-1, the EU standard for short-range devices which would apply to products made with these units, places an absolute limit on all spurious emissions (without making a distinction for harmonics) of 250nW or -36dBm. No chance of that.

The high level of second harmonic is a direct consequence of the cheap design of the circuit. There is no output filtering, and the NPN transistor oscillator-power amplifier with minimal biasing ensures substantial waveform distortion.

Stability and drift

One important factor is the stability and accuracy of the output frequency with time and temperature. Here the use of a SAW resonator is crucial, and the measurements show that there is nothing to worry about on this score. A typical modern SAW (now almost exclusively offered in small surface mount packages) gives a centre frequency spread of ±100kHz and a temperature coefficient of frequency of –0.032 ppm/K^2. The spread of initial frequencies between units is well within the allowed band. At low voltages there is no noticeable drift in frequency; at 12V there is some drift, possibly related to temperature rise from the associated power dissipation, or the burn-in effect discussed below.

[3] You may think this is not by accident, and you'd be right

By comparison with the wide-open receive frequency band (discussed later) any concern about transmit frequency drift is really unnecessary. Strictly, EN 300 220-1 allows no more than 100ppm drift or 43kHz/0.01%, but since the absolute frequency is not specified this is not practicable to enforce.

Power efficiency and supply voltage

Most of the power taken from the supply during transmission of a data '1' does not go into the antenna or, more specifically, into the 50Ω measurement load. If higher efficiency is desirable, you would need to design a matching circuit specific to the antenna that would be used.

The supply voltage range is wide, and is quite an advantage of this design. Certainly it can operate quite happily from 3V and down to 2V without problems, though the power drops off more rapidly at the bottom end; it would probably be possible to operate from a single 1.5V battery if necessary, in very short-range operations, though there isn't much latitude for end-of-life battery voltage drop. It supposedly handles anything up to 12V, though continuous dissipation of up to 0.75W might be asking too much and a low duty cycle would be wise, as well as being a necessity to comply with the licence-exempt regulation if the antenna has any gain.

Burn-in effect

One factor which appears to be a feature with each unit is what might be called a "burn-in" phenomenon. After running at 12V for 3 minutes with continuous power, both the frequency and output power suffered an apparently permanent shift. The frequency shifted downwards towards the band centre while the power reduced. Later testing confirmed that these shifts hadn't recovered, at any supply voltage. This may be an effect of over-driving either the SAW resonator, or the oscillator transistor: if the device is indeed a 2SC3838Q as the marking suggests, it will be overcooked at 12V. If the supply voltage is maintained below 5V there seemed to be no such effect. While the frequency shift would have no impact on system operation, the power reduction might. As a matter of precaution then I wouldn't recommend operating these units at their specified maximum of 12V supply unless it's really necessary, and then check the long-term reliability.

Data frequency response

The specification suggests a data transfer rate of 4kb/s; certainly the standard 4800kbaud rate (208µs bit time) is easily supportable with the measured rise and fall times. 9600kb is probably pushing it but possible, depending on the strength of the link, the response time of the receiver and the decoding software.

The receiver

In contrast to the transmitter, the receiver is harder to make absolute measurements on without an open-field test site. It's a super-regenerative design, which means that the RF front end is held just under the point of oscillation somewhere around the receive frequency. When it encounters a signal, the circuit is prompted into oscillation, creating a DC shift which is amplified and provides the digital output (see the block diagram): high level means RF present, low means no RF. This has several consequences:

- The RF side is essentially wide open, there is no RF filtering at the receive frequency; any signal in the region of the oscillation will trip it, with the sensitivity falling off gradually either side of the maximum response; but "gradually" here means that the response is several MHz wide. It is therefore easily affected by both transient interference and other intentional signals

- The antenna is part of the RF circuit. It is impossible to apply a test signal directly to the front-end from the usual 50Ω signal generator source as this completely kills the super-regen effect. In this case, I applied the test signal from a Marconi 2024 sig gen via a single-turn loop at 2cm from the specified “32CM single core wire, wound into a spiral”. This is near-field coupling and inherently uncertain, and doesn’t give an absolute figure for the sensitivity, but does allow other parameters of the receiver to be measured
- The signal detection threshold is very sensitive to supply voltage, although the circuit does automatically adjust it for maximum sensitivity in the absence of a signal; but an un-regulated supply with poor decoupling will drastically affect the consistency of the sensitivity level.
- The unit is actually generating a low-level wideband oscillation the whole time – see the spectrum analyser plot in Figure 2. This can be seen with a near-field probe close in to the unit, but is at too low a level to affect other units in the 433MHz band; it may or may not meet the EN 300 220-1 limit for spurious emissions.

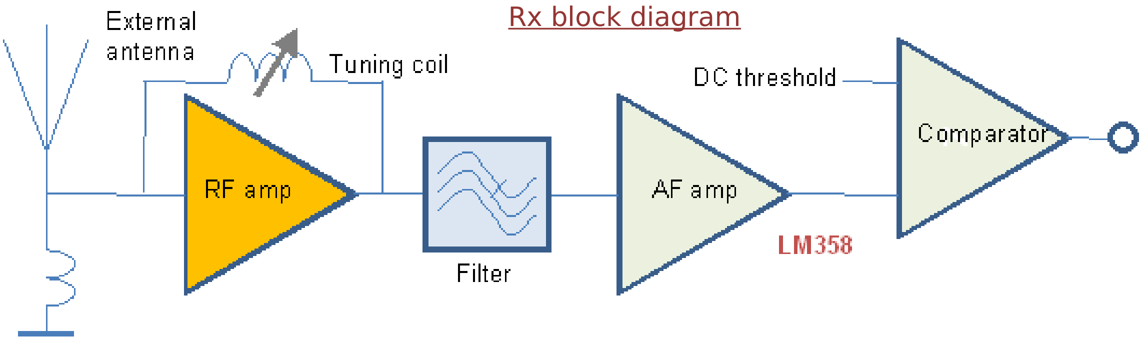
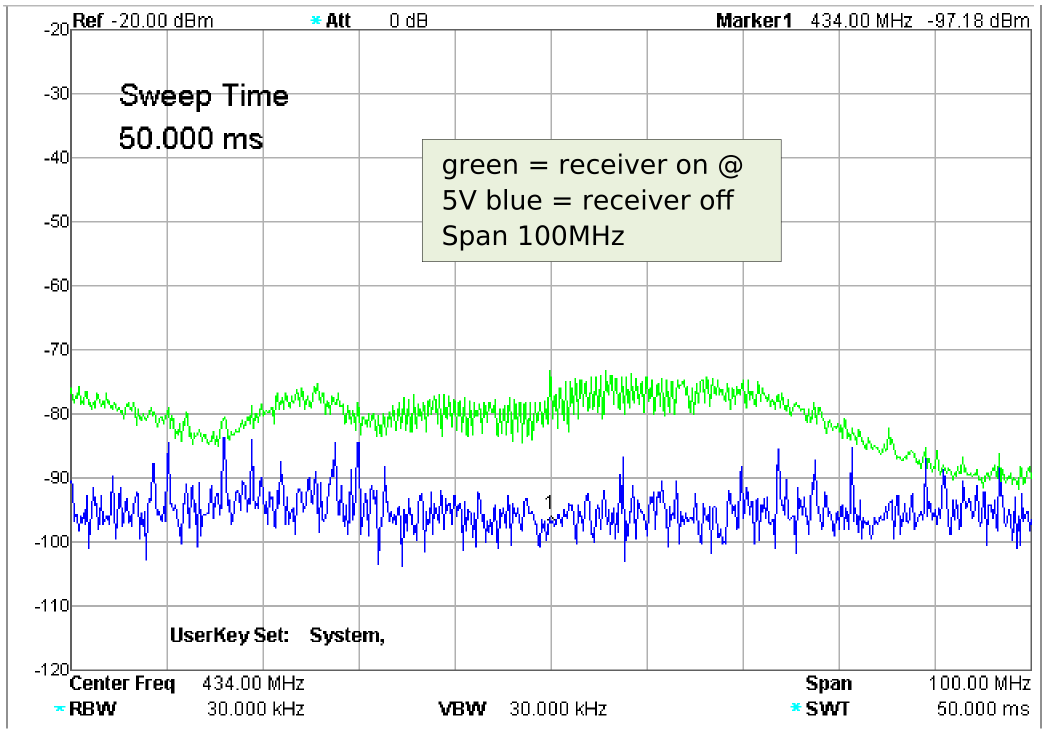


Figure 2. Receiver self-oscillation emission spectrum (near field probe)



It's also worth repeating the somewhat opaque "remark" that goes along with the "specification":

> *1.VCC voltage module operating voltage and good power filtering;*
> *2.Great influence on the antenna module reception, preferably connected to the 1/4 wavelength of the antenna, typically 50 ohm single conductor, the length of the antenna 433M of about 17cm;*
> *3.Antenna position has also affected the reception of the module, the installation, the antenna as possible straight away from the shield, high pressure, and interference source; frequency used to receive, decode and oscillation resistor should match with the transmitter.*

More good advice can hardly be imagined than there is here. Two particular points of interest: point no 1 emphasizes the importance of the VCC supply, as also mentioned in the third bullet point above. Tapping directly off a local microprocessor 5V supply is likely to be unsuccessful, especially if it's from a switch-mode source, because of the accompanying mid-frequency ripple and variation. I've found a 78L05 linear regulator from another supply of 8-12V, together with a 22µF decoupling capacitor, to be satisfactory.

The second point is that point 3 above mentions, in passing, "the shield". Nowhere else is it suggested that a shielded enclosure around this PCB is needed, but again, because of the wide-open sensitivity to all sorts of environmental stresses, it's something that I would definitely recommend; and then, as suggested in point 3, the antenna should not be close-coupled to it.

Measurements

The receiver parameters which have been measured are shown below.

Table 5. Receiver parameters per unit

Note	Characteristic	Unit 1	Unit 2	Unit 3	Unit 4
1	Sensitivity @433.92MHz dBm	-42	-55	-57	-43
2	-6dB sensitivity range MHz	432.8 > 436.08	432.64 > 437.14	432.5 > 436.63	432.52 > 436.2
3	I_{CC} @ 5V, quiescent/50% data, mA	3.19 / 3.23	3.2 / 3.23	3.18 / 3.22	3.2 / 3.24
4	Supply voltage range	4.9 – 5.45	4.75 – 5.25	4.9 – 5.3	4.95 – 5.35

Notes:

1 for just glitch-free reception with tuning coil adjusted approximately. This is dBm into a single-turn coupling link at a fixed distance from the spiral antenna. It only gives an indication of the spread of sensitivity between devices

2 lower > upper frequency range for just glitch-free reception with signal level as per note 1 adjusted +6dB

3 shows how much the supply current changes between quiescent and receiving a 50% duty cycle signal. There is no load on the output pin

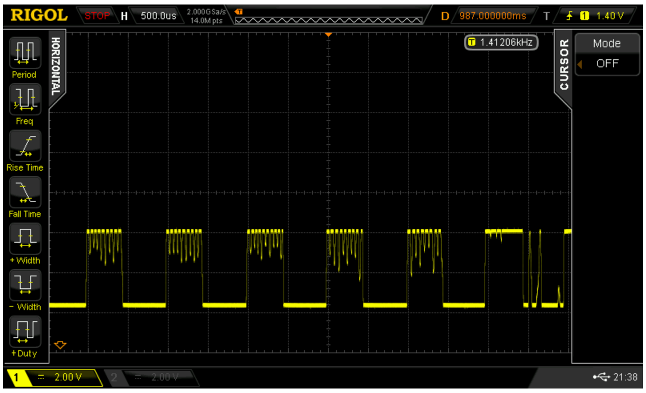
4 to maintain the same sensitivity as at 5.0V and 433.92MHz

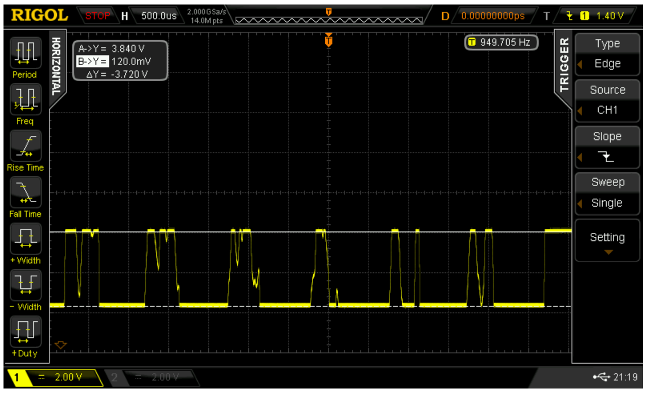
Table 6. Common parameters

O/P voltage pk-pk	3.72	No load
Rise/fall time µs	10	Sig gen = 1µs risetime
Start-up time secs	> 1 sec	Power on to data available

Observations

The results above refer to “just glitch-free reception”. This is as observed on an oscilloscope at the output, a couple of examples where the glitches have become apparent are shown here – the signal generator is modulated with a 1kHz square wave. There is a fraction of a dB difference between the two conditions. If the signal drops by more than a dB, the output disappears completely except for transients related to general RF noise.





The specification refers to a receiver sensitivity of “-105DB” but there is no way of knowing how this has been obtained or what it refers to. Certainly there is no correlation between this figure and the results obtained above.

Supply and output voltage

It was pointed out above that the operation is very sensitive to supply voltage. Item 4 in Table 5 demonstrates the range beyond which the unit loses considerable sensitivity; note that although exactly 5V will be good for all of them, the range isn’t necessarily equal above and below this value, or indeed the same, for each of them. If you’re not sure of the tolerance of the available supply it would be advisable to check it if you’re getting unreliable results, and also make sure it’s well decoupled with a small electrolytic.

The output is taken directly from one half of an LM358, which is an op-amp used as a comparator. This is why it doesn’t swing right up to the supply rail, although it does reach almost down to 0V. If you want it to interface directly with a 3.3V logic input you would need a small resistive attenuator; it will be useable directly with a 5V input, albeit with reduced noise immunity.

The measured rise/fall times are consistent with what is usually observed with the LM358 acting as a comparator. If you need to know any more about the output characteristics, check the data sheet.

Start-up time

Table 6 shows that it takes at least a second between applying power to the receiver and data being available at the output. For many system applications this is not an issue if the supply is continuously present, but it may eliminate those applications where the standby power consumption of 3.2mA is unacceptable such that the receiver can only be powered briefly during an occasional data transmission.

Conclusions

Overall these measurements have given some idea of the performance of the kit over and beyond the published data. At the price you pay for the pair you needn't expect dramatically good performance, and that's fine, because you haven't got it.

The deficiencies of the transmitter are principally the high level of second harmonic output and the poor efficiency, as well as the unusual burn-in characteristic at the higher voltage. Frequency stability is more than adequate and the wide range of operating voltage is a plus.

For the receiver, there are more criticisms; while it does work when the applied signal is high enough, it's hard to know how high this threshold is, and it will be very dependent on the nature of the antenna and its matching, if any. It is wide open to any and all interfering signals in the near environment and so any system implementation software would need to be able to cope with this. It is also intolerant of supply voltage excursions and would require some degree of shielding.

For a hobbyist playing around with short-range remote control, this kit is OK for a starter, but will probably prompt a move to a more robust system once experience is gained. It's not an answer for professional applications, but then it's not marketed at these.