Wireless Microphone

Audio in the ISM band

Ton Giesberts

When the ISM frequency band was made available in Europe for audio applications, Circuit Design, a manufacturer of professional RF modules, decided to develop suitable high-quality transmitters and receivers with a wide dynamic range: these are ideal for use in wireless microphones.

The WA-TX-01 (transmitter) and WA-RX-01 (receiver) modules represent a novel concept in the wireless transmission of audio signals. Thanks to low power consumption, the technology lends itself to a wide range of audio applications. The transmitter and the receiver include components such as SAW filters, SAW resonators and noise reduction ICs.
These key components allow the development of small high-quality audio modules in accordance with European radio regulations and with EMC and R&TTE guidelines. This means that a wireless link can be added to an audio device without having to worry about a complicated, expensive and time-consuming certification process. The frequency channel used by each module is fixed, but there are four separate channels available in the band from 863 MHz to 865 MHz, and so multiple systems can coexist in the same location.

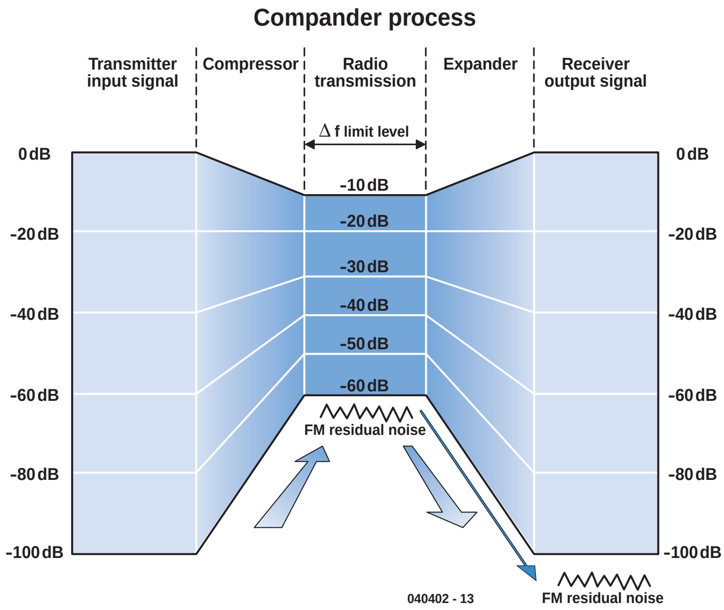
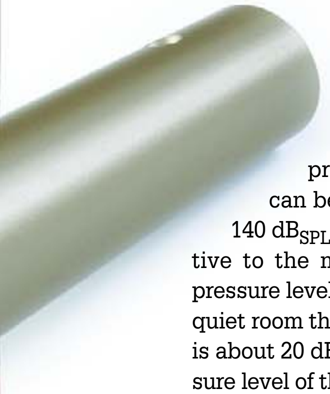


Figure 1. Use of a compander for noise reduction.



Dynamic transmission

The maximum sound pressure level (SPL) which can be tolerated by humans is 140 dB_{SPL}, which is measured relative to the minimum audible sound pressure level of 0 dB_{SPL} = 20 μPa. In a quiet room the background noise level is about 20 dB_{SPL}, and the sound pressure level of the human voice is around 120 dB_{SPL}. It can therefore be seen that the dynamic range required for a normal wireless audio transmission system is around 100 dB.
If an audio frequency of 15 kHz is transmitted using analogue frequency modulation, the required bandwidth (*BW*) is given by:

BW =
2 (maximum frequency deviation + maximum modulation frequency) [Hz]

Unfortunately any FM circuit must suffer from residual sideband noise originating in the PLL or crystal oscillator. As a rule of thumb, we can reckon with a residual noise, measured in terms of frequency shift, of around 50 Hz. For a dynamic range of 100 dB (i.e., a factor of 100 000), we therefore need an overall frequency deviation of 50 × 100 000 = 5 MHz. As you might expect, this means that the required bandwidth is much greater than that available in this application. For comparison, FM radio transmissions make do with a maximum deviation of 75 kHz in a bandwidth of 180 kHz (mono) or 264 kHz (stereo plus traffic data).
In order to solve this problem while keeping within the legal restrictions on frequency deviation, a compressor is built into the transmitter and an expander into the receiver. This technique is called a compander noise reduction system (**Figure 1**).
The Dolby noise reduction system varies the compression ratio with frequency. The compander noise reduction system used here, on the other hand, fixes the compression ratio at 2:1 over the entire frequency range, thus halving the dynamic range of the signal. In the expander, whose ratio is set to 1:2, the exact opposite occurs, and the dynamic range is doubled again. A dynamic range of 100 dB is thus reduced to 50 dB for transmission.
We can now recalculate the frequency deviation required. With a residual noise of 50 Hz we need a frequency deviation of 500 Hz for a 20 dB dynamic range, 5 kHz for 40 dB, and 20 kHz for 52 dB. A wireless system with a signal-to-noise ratio of 50 dB can carry sound signals with an original dynamic range of 100 dB.
Why, in this ‘digital age’, do we employ analogue transmission techniques for the wireless microphone rather than, for example, PCM? There are several reasons. Many countries have not allocated a dedicated frequency band for digital wireless microphones. Digital transmissions using PCM require a wide frequency band, which is not readily available below 1 GHz. Above 1 GHz ‘dead spots’ start to appear, meaning that these frequencies are not suitable for live use where the performer may move around between various positions on stage. Finally, conversion to digital requires much more power, making it less practical to run the device from small batteries.

If desired, the modules (both receiver and transmitter) can be operated from a 1.5 V battery via a low-noise DC-DC converter available from Circuit Design. In order to achieve the 100 dB dynamic range that is possible with the wireless microphone, the noise produced by the DC-DC converter muct be less than –60 dBm. The WA-DC-01 DC-DC converter requires an input voltage of at least 0.9 V and can produce an output voltage of 3 V at the maximum load current of 50 mA.

The transmitter

Figure 2 shows the functional blocks of the WA-TX-01 transmitter. We will look at each in turn.

Input buffer (BUF)

This circuit is an input buffer for the microphone capsule or other sound signal source. The maximum input level is –15 dBV and the input impedance is 7.5 kΩ. If the maximum output level of the signal source is not sufficient, a low-noise amplifier must be connected before the buffer. If the signal source level is too high, an attenuator should be used.

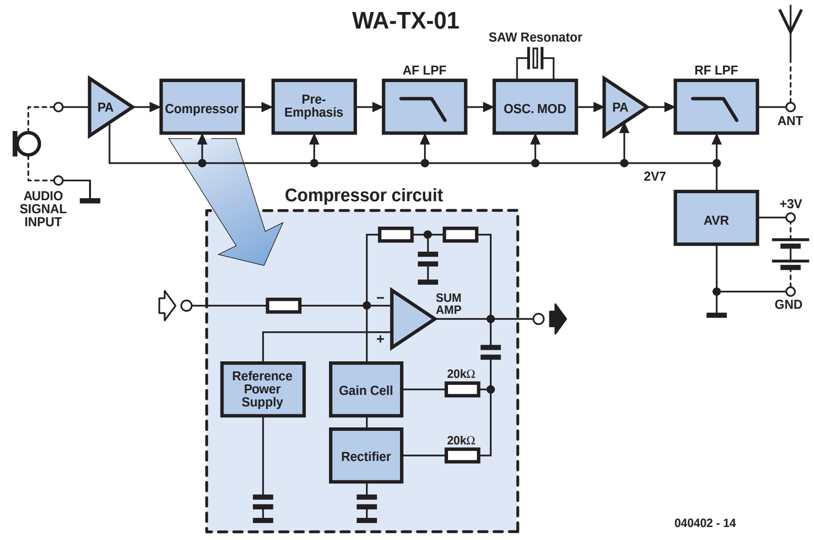


Figure 2. Block diagram of the transmitter module...

Compressor
The audio signal from the buffer stage is compressed using a ratio of 2:1. The compressor consists of a reference generator, a full-wave rectifier and a summing amplifier. The reference generator provides a bias voltage and a constant current to the other parts of the circuit.
The full-wave rectifier circuit rectifies the incoming signal with the aid of an external capacitor. The output current of the rectifier controls the gain cell amplifier. The time constant of the control loop is set, in part, using an external filter capacitor and an internal 10 kΩ resistor. The summing amplifier adds the incoming signal and the signal from the gain cell amplifier together. The summing amplifier used in the compressor needs different properties from the one used in the expander, and so different components are used in the transmitter and in the receiver.

Pre-emphasis
To reduce noise at the upper end of the audio frequency range, which is a particular problem when using frequency modulation, this circuit boosts higher frequencies using a time constant of 50 μs.

AF low-pass filter (AF LPF)
This circuit limits the bandwidth of the audio signal in order to ensure that interference to adjacent channels is kept within the permitted limits.

Oscillator and modulator
In order to operate directly in the 800 MHz band, a crystal-based SAW (surface acoustic wave) filter resonator with good temperature stability is used as the oscillating element. Frequency modulation is achieved using a varicap diode that forms part of the oscillator circuit.

RF power amplifier (PA)
This circuit steps the RF output of the oscillator up to the transmit power of about 5 mW.

RF low-pass filter (RF LPF)
This circuit attenuates the second and higher harmonics of the transmitted signal and provides antenna impedance matching.

Voltage regulator (AVR)
This circuit provides a stable 2.7 V supply for the whole circuit. It operates from a battery supply of between 3 V and 9 V.

The receiver

The block diagram of the WA-RX-01 receiver module shown in **Figure 3** is practically the mirror image of the transmitter, using similar components.

RF band-pass filter (SAW)
The 800 MHz frequency band used in this wireless audio system is extracted using this filter. A high-selectivity SAW

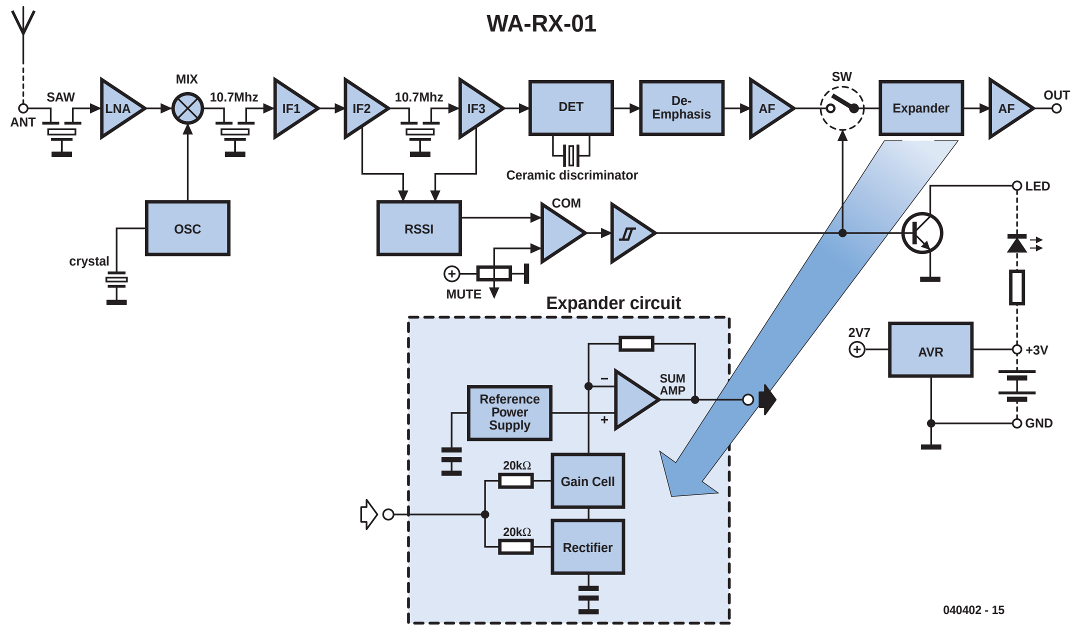


Figure 3. ... and of the receiver module.

filter is used to ensure that frequencies outside the band are eliminated.

Oscillator (OSC)
A quartz crystal oscillator is used to mix the incoming signal down to an intermediate frequency of 10.7 MHz.

RF amplifier (LNA)
A low-noise amplifier is used to amplify the 800 MHz frequency band by 10 dB.

Mixer (MIX)
This circuit creates an intermediate frequency of 10.7 MHz, produced by mixing the amplified received signal in the 800 MHz band with the output of the oscillator.

IF amplifier (IF1 to IF3)
These provide a total gain of 100 dB, the final stage acting as a limiter. Before and after the amplifier chain, 10.7 MHz ceramic filters are fitted to provide selectivity.

FM detector (DET)
This circuit demodulates the frequency-modulated IF signal.

RSSI detector (RSSI)
Signals from the middle of the IF amplifier chain are rectified producing a DC voltage proportional to the signal strength.

Muting comparator (COM)
The RSSI signal is compared to a preset voltage which can be adjusted using a potentiometer. If the level at the antenna input falls to 17 dBμV or less, the output signal is turned off.

De-emphasis
This compensates for the 50 μs pre-emphasis, making the overall frequency response of the system flat.

AF amplifier (AF)
This circuit amplifies the demodulated audio signal before it is passed to the expander.

Analogue switch (SW)
If the signal strength falls too far, the audio signal is muted using this switch. An LED indicates when this muting occurs.

Expander
The dynamic range of the audio signal is doubled by this circuit, which operates in much the same way as the compressor.

AF output amplifier (AF)
The output of the expander circuit is amplified again for output.

Voltage regulator (AVR)
This circuit provides the entire circuit with a stable 2.7 V supply from a battery voltage of between 3 V and 12 V.

Interface

Thanks to these complex modules that include almost all the necessary electronics, what remains is straightforward. **Figure 4** shows the two parts of the circuit. In the transmitter we can either connect a microphone or any other desired audio source with a maximum output level of –15 dBV. In most cases, however, an electret microphone will be used. There is a small offset voltage present at the AF input with P1 adjusted to maximum: in our prototype we measured about 0.15 V. If a dynamic microphone is to be connected, it is essential to add a coupling capacitor. Alternatively, omit R1 and connect the dynamic microphone in place of the electret microphone. P1 can be used to attenuate microphone signals that are too high, so that the radio module is not overdriven.

The receiver circuit is slightly less simple. The receiver module has two outputs, one for the signal itself and one which indicates whether the signal strength is adequate or whether the muting circuit has been triggered. Since we have plenty of power to spare at the receiver (battery operation here is not essential) we can afford an extra indicator in the form of LED D1.

In order to amplify the output of the receiver module (which, at 10 kΩ, is not exactly low impedance), we have added a buffer amplifier. This is a classical non-inverting AC amplifier built around a rail-to-rail opamp which can operate from a voltage of between 2.7 V and 12 V, almost the same range as for the module. We have shown a supply voltage of 5 V, although 3 V or 12 V would do just as well. If a different (non-rail-to-rail) opamp were used, a supply voltage of 5 V would be required. Many opamps will only operate correctly with a symmetric power supply of ±5 V or

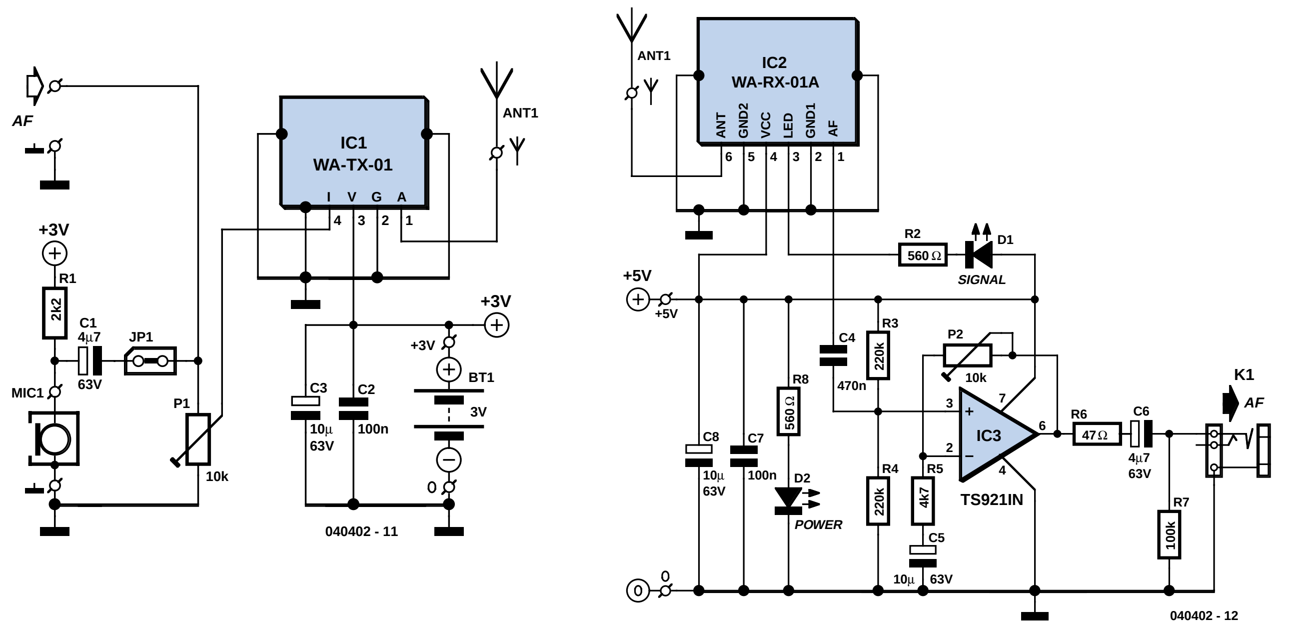


Figure 4. Interfaces for the radio modules.

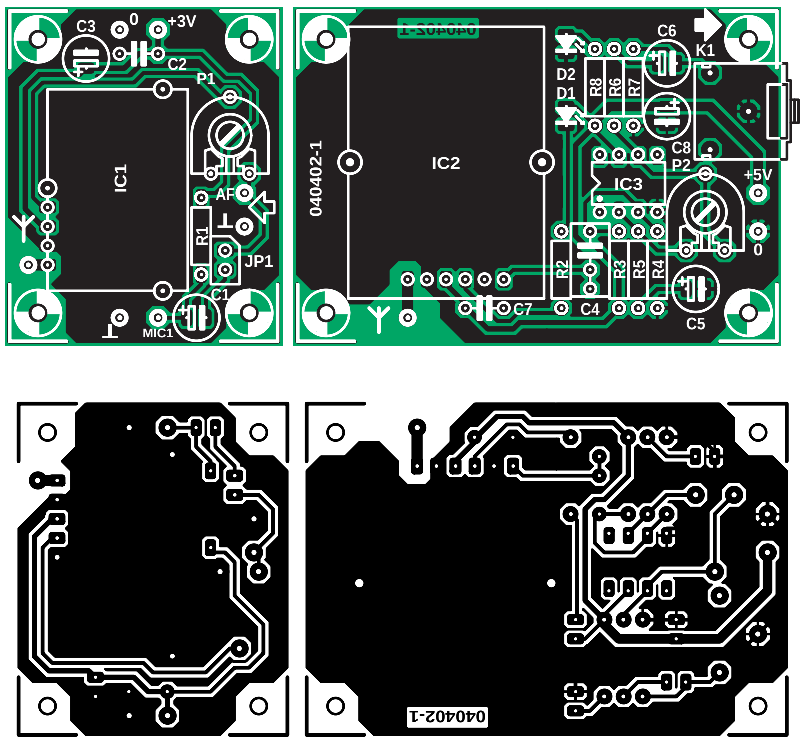


Figure 5. Two circuit boards make one radio link.

COMPONENTS LIST

Resistors:
R1 = 2kΩ2
R2,R8 = 560Ω*
R3,R4 = 220kΩ
R5 = 4kΩ7
R6 = 47Ω
R7 = 100kΩ
P1,P2 = 10 kΩ preset

Capacitors:
C1,C6 = 4µF7 63V radial
C2,C7 = 100nF
C3,C5,C8 = 10µF 63V radial
C4 = 470nF

Semiconductors:
D1 = LED, 3mm, green, low current
D2 = LED, 3mm, red, low current
IC1 = WA-TX-01 (Circuit Design)
IC2 = WA-RX-01A (Circuit Design)
IC3 = TS921IN (or equivalent rail-to-rail opamp)

Miscellaneous:
JP1 = 2-way pinheader with jumper (angled if necessary)
K1 = 3.5-mm jack socket, PCB mount (e.g. Conrad Electronics # 732893)
BT1 = battery holder for two 1.5V batteries
MIC1 = electret microphone
PCB, no. 040402-1, available from The PCBShop

with an asymmetric 10 V supply. A further advantage of the TS921 used here is its high output drive capability: it can directly drive headphones or even two 32 Ω headphone transducers wired in parallel, although in this case C6 should be replaced by a 100 µF 10 V type. The 47 Ω output resistor protects the opamp from the inductive load of a shielded cable and from short circuits. Trimmer potentiometer P2 allows the gain to be adjusted from unity (P2 at minimum resistance) to 10 dB (P2 at maximum resistance). C6 removes any DC component from the output and R7 ensures that there is always a load at the output. Since the opamp has asymmetrical supplies, a capacitor (C5) is also required in the feedback circuit. R3 and R4 set the operating point of the opamp at half the supply voltage. C7 and C8 provide extra power supply decoupling. At higher supply voltages it is necessary to increase the current-limiting resistors for the low-current LEDs so that the current through them does not exceed about 2 mA.

We have designed a two-part printed circuit board to accommodate the radio modules and the few external components (**Figure 5**). The layout is designed for optimum audio performance.

The components should be fitted to the board, observing that the transmitter module can only be fitted to the copper side. An ordinary 3.5 mm jack socket provides the audio output.

All that remains are the antennas. In principle a stiff piece of wire with length 1/4 λ (78 mm at 860 MHz) will do the job; more professional antennas can be found on the Circuit Design website at http://www.cdt21.com/.

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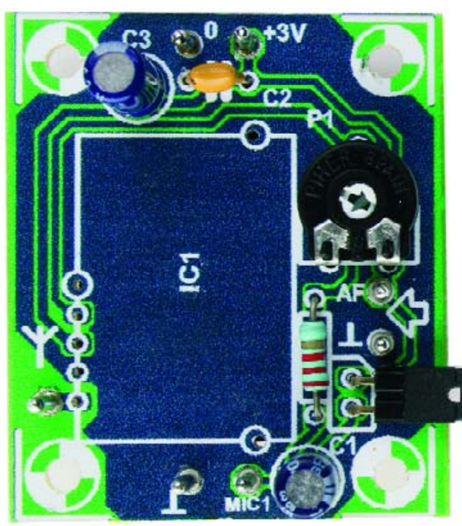
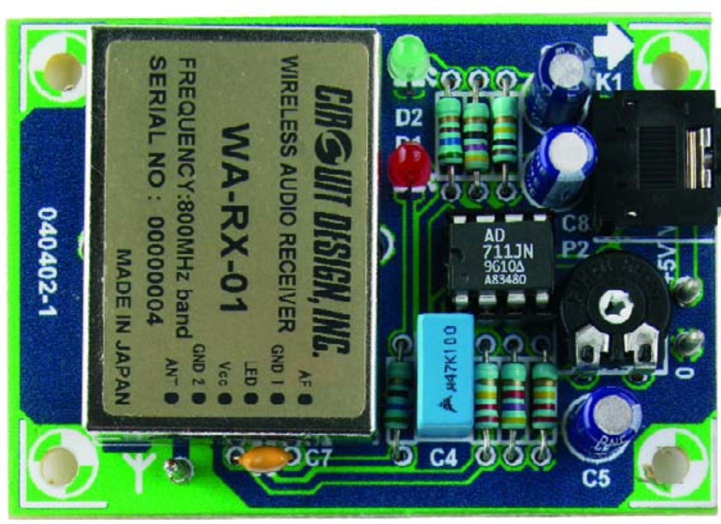




Frequency	863.125 MHz; 863.625 MHz; 864.500 MHz; 864.875 MHz
RF channels	one (fixed)
Emission code	F3E
Range	approx. 50 m line-of-sight
Signal-to-noise ratio	90 dB (with IHF-A filter)
Audio frequency range	50 Hz to 15 kHz ± 3.5 dB (output level –50 dBV ± 3 dB)
THD	2 % (@ AF 1 kHz, deviation = 15 kHz or 7.5 kHz)
Pre-emphasis	50 µs
Operating temperature	0 °C to 50 °C

Transmitter

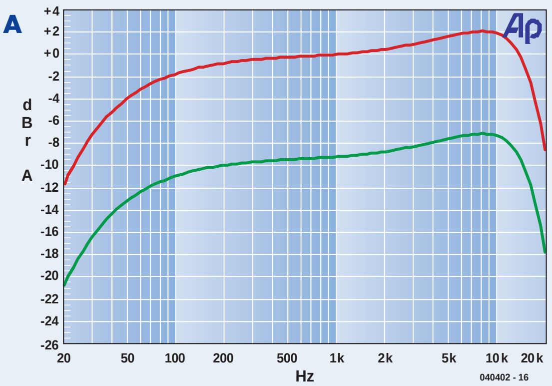
Oscillator	SAW oscillator, crystal-based
RF power	2 mW
Frequency stability	±10 kHz
Pre-emphasis	50 µs
Noise reduction	Compressor
Spurious emission	1 µW maximum
Deviation	15 kHz (1 kHz @ –25 dBV)
Audio input level	–115 dBV to –15 dBV (1 kHz)
Audio input impedance	5 kΩ
Supply voltage	3 V to 9 V
Maximum module current consumption	25 mA
Measured current consumption	17 mA @ 3 V

Receiver

Receiver type	Superheterodyne
Mixer oscillator	Crystal-controlled
Intermediate frequency	10.7 MHz
Noise reduction	Expander
Sensitivity	21 dBµV (@ THD 2 %)
Squelch sensitivity	17 dBµV ±4 dB
Audio output level (at module)	–20 dBV (deviation = 15 kHz) Maximum –10 dBV (deviation = 30 kHz)
Audio output impedance (at module)	10 kΩ
Supply voltage	3 V to 12 V
Maximum module current consumption	30 mA
Measured current consumption (D2 on, R2 = R3 = 560 Ω)	32 mA @ 3 V 40 mA @ 5 V 52 mA @ 9 V

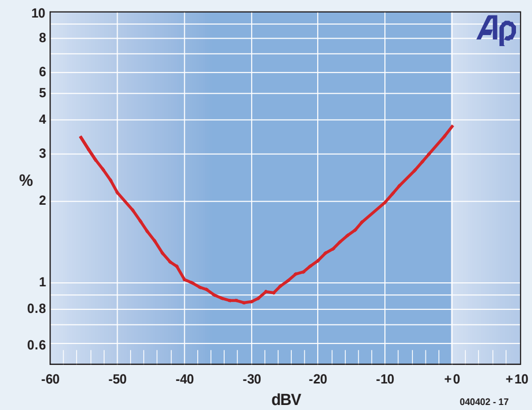
Note: 0 dBV = 0.775 V

A



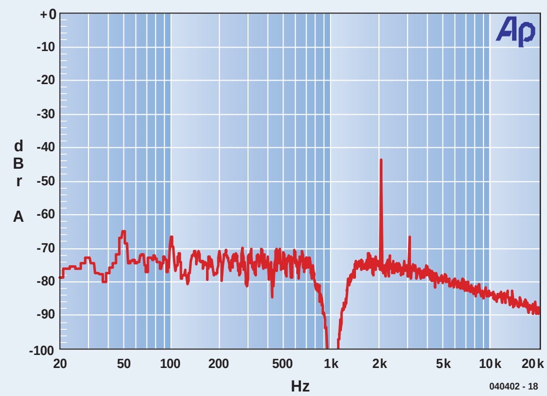
Curve A shows the overall transfer characteristic of the entire radio link, measured at minimum gain (green) and maximum gain (red). The input signal to the transmitter was at –46 dBV (approximately 5 mV). The output signal at maximum gain was at –31 dBV. The output signal of the receiver is 5 dB above the input level to the transmitter. With a higher input signal level the response falls off somewhat at higher frequencies, but the amplitude at 5.5 kHz is up to 3 dB higher than that at 1 kHz.

B

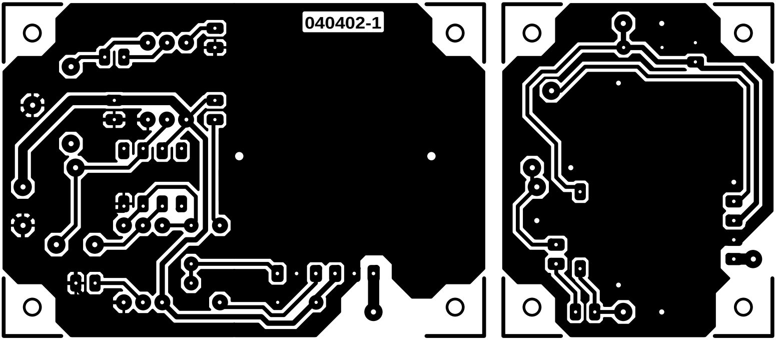


Curve B shows the distortion (plus noise) at the output of the receiver against signal level, measured over the frequency range from 22 Hz to 22 kHz. The optimum value appears to occur with an input signal level at the transmitter of 5 mV. In this case the input signal is raised from –70 dBV to –15 dBV with the gain at the receiver is at a maximum. This is more than adequate for speech signals.

C



Curve C shows the frequency spectrum with an input signal level at the transmitter of 5 mV. Most of the distortion is at the second harmonic. In this case the THD+N figure is 0.85 % (over the frequency range from 22 Hz to 22 kHz).



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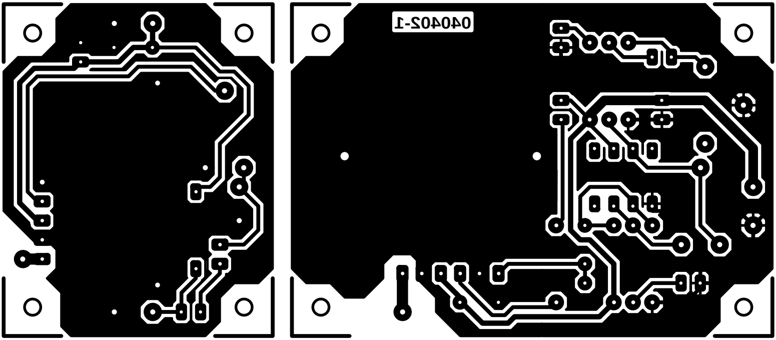

reflected