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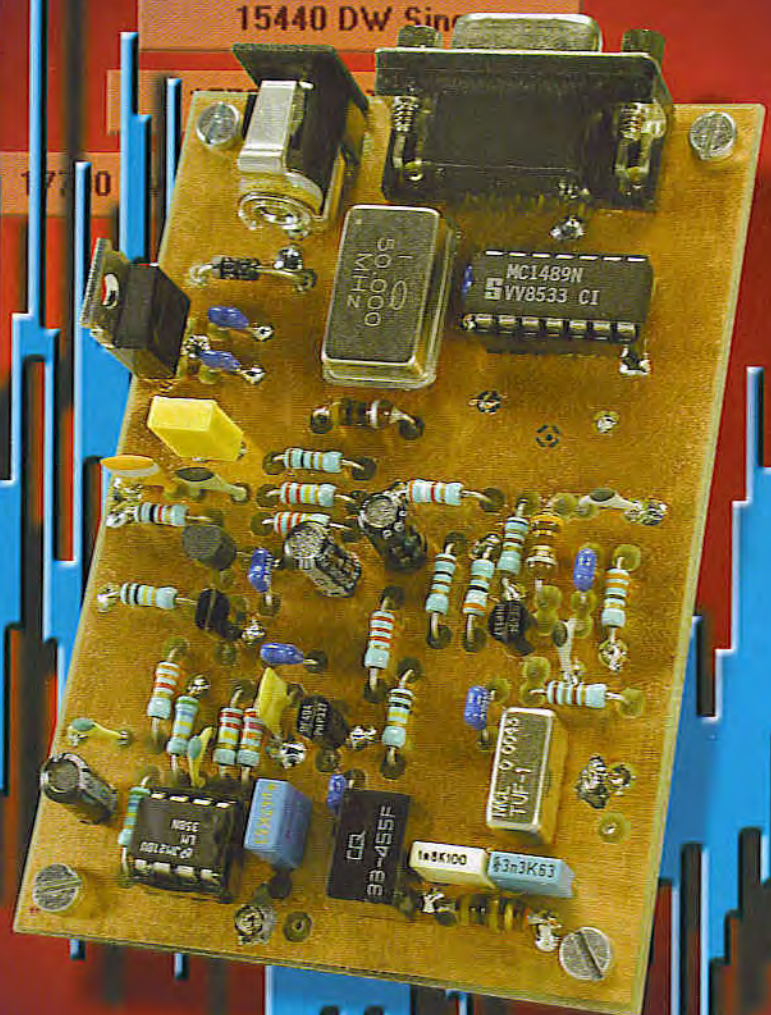
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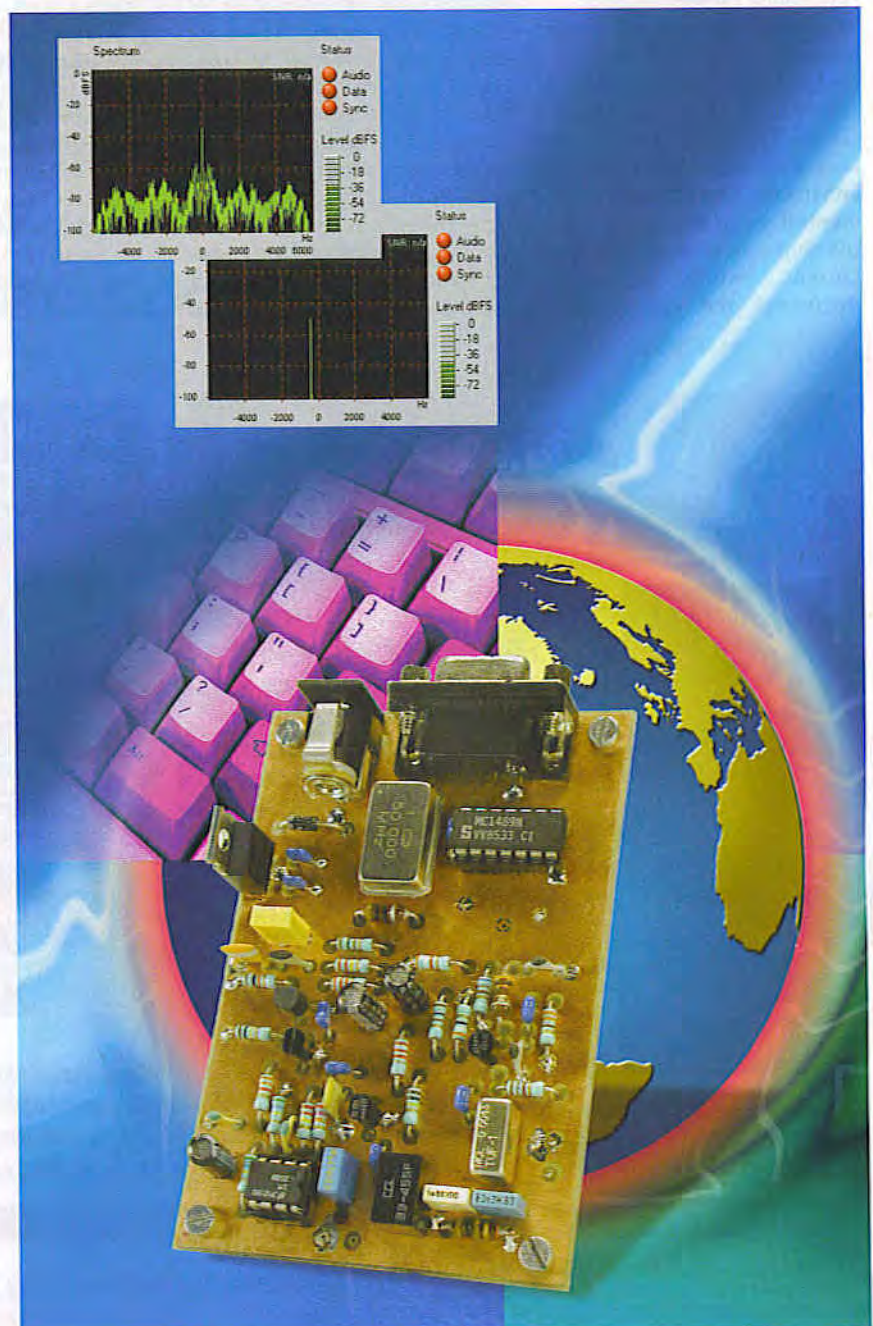


Build Your Own DRM Receiver

A digital radio for 500 kHz to 22 MHz

Design by B. Kainka

One again Elektor Electronics makes its competitors take a very distant back seat by publishing the world's first homebuilt DRM receiver for digital (MP4-quality) broadcasts in the medium and shortwave bands. The receiver is of a surprisingly simple design and supplies a 12-kHz output signal for easy connection to your PC's soundcard which handles the demodulation and MPEG decoding. The receiver is also tuned by the PC via an RS232 link.



On 15 December 2003, DRM (Digital Radio Mondial) entered a new phase on the shortwave and medium-wave bands. The encoding was changed to MP4 in order to improve the quality of the received audio signals even further. The unique receiver described in this article was developed for all readers interested in listening to DRM broadcasts at a modest investment.

One of the targets set for the design was good receiver performance without any adjustment points. No special inductors or tuning capacitors are used in this project, just off-the-shelf fixed inductors. This, we hope, encourages those readers with more experience in digital electronics than RF design and construction. There's no adjustment to worry about and no need for special test equipment. A very simple software-driven alignment is sufficient to illuminate tolerances in the oscillator frequencies used in the circuit.

The basic operation of DRM and in particular its signal encoding and transmission method was described in *Elektor Electronics* December 2002 [1]. Exactly one year later, in the December 2003 issue [2] we ran an article describing how DRM signals could be picked up and turned into audio using an experimental receiver based on our DDS RF Signal Generator and a PC or notebook. The present DRM receiver also contains a DDS (direct digital synthesis) chip. The two articles mentioned above provide a good technical background to the workings of DRM and were published at a time when none of our competitors was able to come up with technical specifications on DRM let alone an experimental yet reproducible receiver. The publication of this article is sure to increase the distance.

A DRM interface

It is perfectly possible to view the receiver as a DRM interface for the PC. As illustrated in **Figure 1a**, the DRM receiver has two links to the PC. By way of an RS232 connection, it gets digital control information for tuning the DDS to the desired DRM broadcast station.

As opposed to a normal radio or

general coverage receiver the DRM receiver does not supply an audio signal you can make audible using analogue means like headphones, a loudspeaker or an audio amplifier. Internally, the DRM receiver mixes the signal received from the DRM station down to an IF (intermediate frequency) of 12 kHz. Its output therefore supplies a mix of modulated carriers that together convey the audio signal in the form of a digital datastream. This DRM spectrum, a mix of various frequencies covering a bandwidth of 10 kHz, is connected to the Line input of the PC soundcard. Alternatively the Microphone input may be used if the signal is rather weak. The DRM signal is digitised by the soundcard, while a special DRM receiver program looks after the demodulating of the DRM signal as well as the decoding of the MP4 datastream. Again, all demodulation and decoding is done in software. The resulting hi-fi stereo audio signal is then available at the output of the soundcard for reproducing by a (PC) loudspeaker or headphones.

Double-conversion

As you can see from the block diagram (**Figure 1b**), the signal received from the DRM station is mixed two

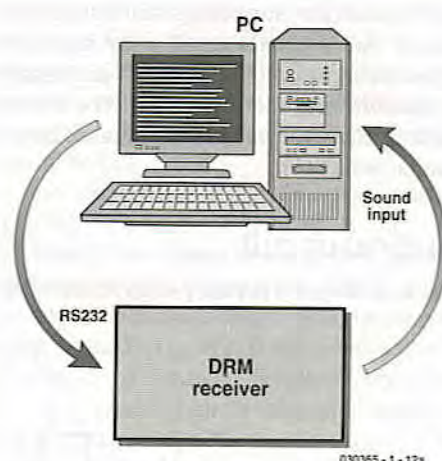


Figure 1a. The DRM receiver has two connections to the PC: a serial link for the receiver tuning and a connection feeding an MPEG datastream to the Line or Microphone input on the soundcard. All decoding and demodulation is done in software.

times — first, a variable oscillator frequency is used to mix it down to a fixed intermediate frequency (IF) of 455 kHz. This provides the station tuning on the receiver. The second heterodyning operation is against a fixed 467 kHz signal in order to mix the 455-kHz signal down to 12 kHz. Using receiver terminology, the DRM receiver is a 'double-conversion' or 'super-heterodyne' type. The first injection signal is obtained from a synthe-

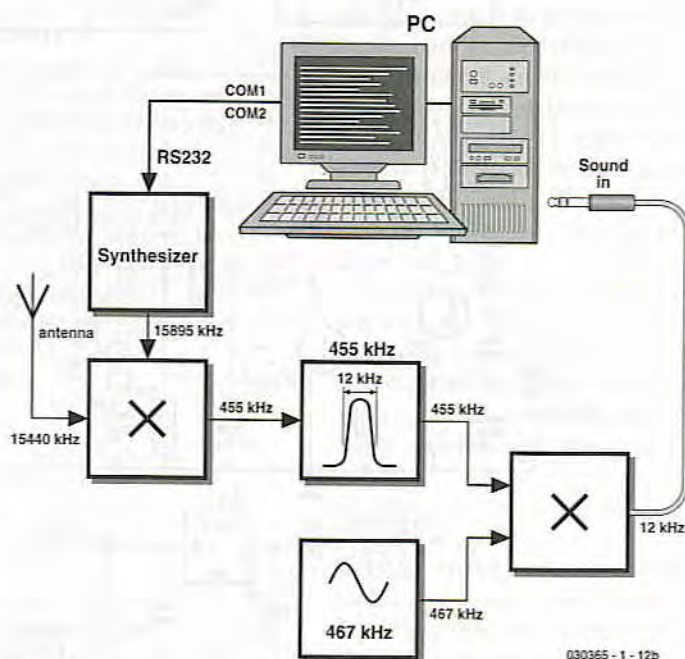


Figure 1b. The block diagram of the DRM receiver reveals a double-conversion ('super-heterodyne') design with intermediate frequencies at 455 kHz and 12 kHz.

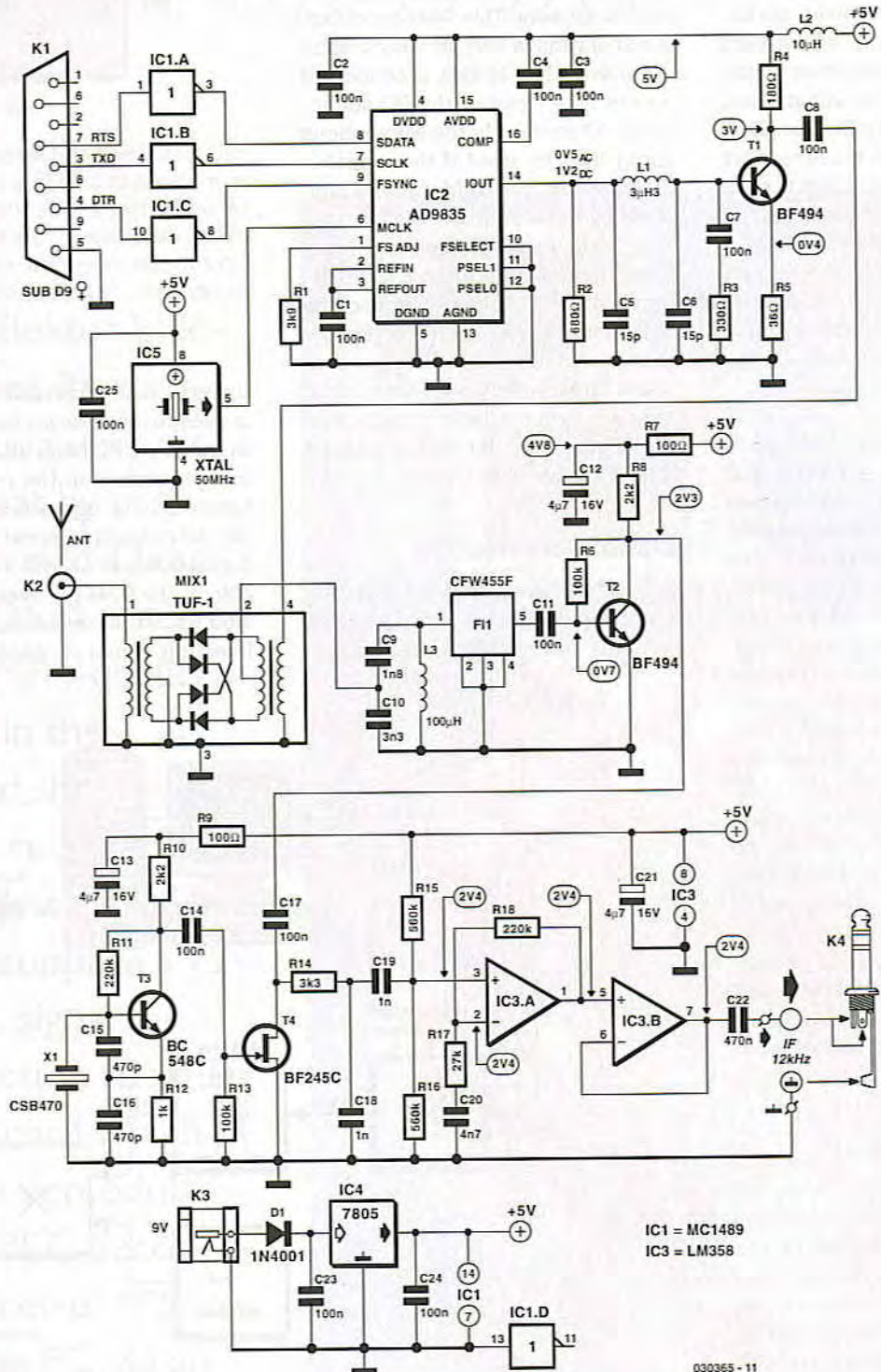
sised oscillator supplying an output frequency that's programmable by means of control data generated on the PC and sent to the receiver over the RS232 link. The second injection signal at 467 kHz originates from a ceramic resonator.

Practical circuit

The block diagram is easily found back in the

circuit diagram shown in **Figure 2**. The DDS oscillator based around IC2 supplies an output signal to the first mixer (MIX1) via a buffer stage, T1. In case you've never seen such a beast, MIX1 is a wideband double-balanced diode ring mixer. The IF signal at 455 kHz is taken through a steep ceramic filter (F11) with 12-kHz bandwidth. An IF amplifier stage

around T2 raises the level by about 20 dB before the signal is applied to the second mixer comprising (passive) FET T4, a type BF245. The second injection oscillator is frequency-stabilised by a CSB470 ceramic resonator (X1) whose nominal output frequency is pulled down by 3 kHz to arrive at 467 kHz. The 12-kHz IF signal at the drain of T4 goes through a



IC1 = MC1489
IC3 = LM358

030365 - 11

Figure 2. The practical circuit of the DRM receiver is marked by PC-driven tuning of a DDS oscillator and two large-signal resistant mixers.

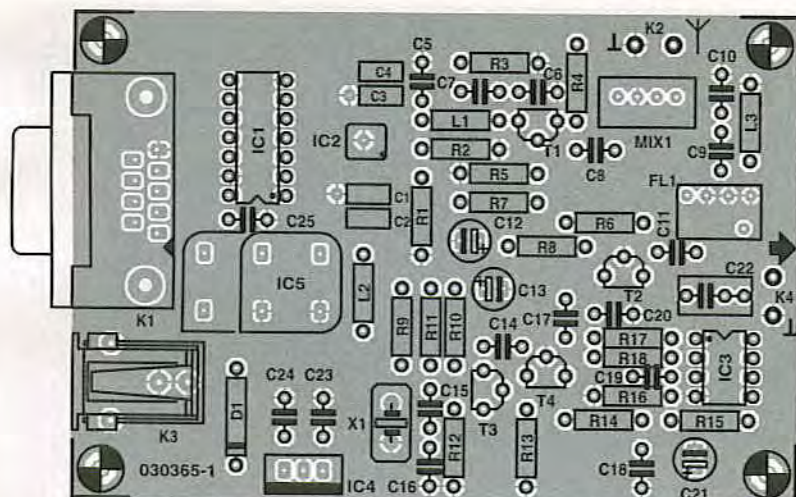


Figure 3. The PCB is double-sided and through-plated. All parts in the RF sections have to be soldered with the shortest possible lead lengths.

COMPONENTS LIST

Resistors:

R1 = 3k Ω
 R2 = 680 Ω
 R3 = 330 Ω
 R4 = 180 Ω
 R5 = 39 Ω
 R6, R13 = 100k Ω
 R7, R9 = 100 Ω
 R8, R10 = 2k Ω
 R11 = 220k Ω
 R12 = 1k Ω
 R14 = 3k Ω
 R15, R16 = 560k Ω
 R17 = 27k Ω
 R18 = 220k Ω

Capacitors:

C1-C4 = 100nF, SMD, case shape 1208
 C5, C6 = 15pF
 C7, C8, C11, C14, C17, C23, C24, C25 = 100nF, lead pitch 5mm
 C9 = 1nF8, lead pitch 5mm
 C10 = 3nF3, lead pitch 5mm
 C12, C13, C21 = 4 μ F7 16V radial
 C15, C16 = 470pF
 C18, C19 = 1nF, lead pitch 5mm
 C20 = 4nF7, lead pitch 5mm
 C22 = 470nF

Inductors

L1 = 3 μ H3
 L2 = 10 μ H
 L3 = 100 μ H

Semiconductors:

D1 = 1N4001
 T1, T2 = BF494
 T3 = BC548C, BC549C or BC550C

T4 = BF245C

IC1 = MC1489N
 IC2 = AD9835 BRU (Analog Devices)
 IC3 = LM358N
 IC4 = 7805
 IC5 = 50MHz oscillator module in 8-way or 14-way DIP case

Miscellaneous:

K1 = 9-way sub-D socket (female), angled pins, PCB mount
 K2 = 2 solder pins
 K3 = mains adapter socket
 K4 = cable with 3.5-mm mono or stereo jack plug
 MIX1 = TUF-1 (Mini Circuits)
 FL1 = CFW455F (455kHz ceramic filter, bandwidth 12kHz) (Murata)
 X1 = CSB470 (470kHz ceramic resonator) (Murata)
 RS232 cable with 1:1 pin connections, plug and socket, no zero-modem or crossed wire cable.
 PCB, order code **030365-1***
 Disk, PC software DRM.exe, order code **030365-11*** or **Free Download**

* see Readers Services page or visit www.elektor-electronics.co.uk

Suggested component / kit suppliers:

- Geist Electronic (www.geist-electronic.de)
- Segor electronics (www.segor.de).
- AK Modul Bus (www.ak-modul-bus.de)

simple bandpass filter before it is buffered and amplified for another 20 dB by two opamps, IC3.A and IC3.B. The output of the second opamp supplies the MPEG data-stream to the PC soundcard input via coupling capacitor C22.

The nitty-gritty of DRM reception is not stability or even spectral purity but **extremely low phase noise of the injection oscillator**. In this respect the DDS VFO gets full marks because it fully meets this requirement, hence our DIY DRM receiver is an excellent performer. Another important design consideration, large-signal response, is fully covered by the passive double-balanced mixer used. The results obtained from our prototype were impressive, to say the least: with a simple wire antenna connected to the receiver input, the DRM software achieves 30 dB quieting, a value only matched by expensive receivers.

Because a couple of characteristics that are crucial in the context of AM reception are less important with DRM, the circuit is able to achieve such excellent results despite the heavily simplified and alignment-free realisation.

The joint dynamic range of the DRM software and the PC soundcard is sufficient to cope with signal variations of up to 30 dB, which are not uncommon on SW and MW. This conveniently saves on an ALC (automatic loudness control) circuit. High receiver sensitivity is not an issue for DRM. Very weak DRM signals (say, below 10 μ V) do not improve by increasing the receiver gain because the actual signal to noise ratio is insufficient at a large bandwidth like 10 kHz. A number of practical tests proved that the receiver can make do without a tuned front-end. For one, the image frequencies at a distance of 910 kHz (2 x 455 kHz) will nearly always fall outside the neighbouring broadcast bands. On the other hand, the DRM software is remarkably tolerant of interference thrown at it.

Of course, the above considerations should not keep you from using a preselector and a matching antenna if you have a fine combination available. If not, rest assured that a 3-10 m long free-hanging wire is sufficient for direct connection to the mixer RF input.

Details

The antenna input directly on the double-balanced TUF-1 mixer has an impedance of 50 Ω . The mixer does the frequency conversion to 455 kHz at a low impedance. The TUF-1 is designed for a frequency range of 2-600 MHz. However, it may operate below 2 MHz with some reduction in the input impedance and

the occurrence of a strong inductive component. In practice, however, the receiver was found to work satisfactorily even down to 500 kHz in the MW range.

The output of the ring mixer is connected to a wideband matching network for 455 kHz. The impedance is stepped up using a resonant circuit with a 1:10 ratio capacitive tap. The result is an impedance of about 1 k Ω to suit the CFW455F ceramic filter. High accuracy is not an issue here because the actual antenna impedance will typically be higher than 50 Ω . The resonant circuit employs a fixed 100- μ H inductor with a low Q factor (<10), ensuring a bandwidth greater than about 50 kHz yet avoiding component tolerance issues. Consequently, no alignment is required on the inductor while the step-up matching circuit still adds to the remote signal rejection of the IF filter.

The CFW455F has a bandwidth of 10 kHz, with 10 kHz being occupied by DRM and the remaining 2 kHz, well, harmless. Actually, a little more bandwidth is important to have as it provides a way of compensating frequency deviations of the second injection oscillator. For example, if the oscillator runs at 467.5 kHz instead of 467.0 kHz, the first IF is automatically shifted up to 455.5 kHz, which may be countered by the software retuning the DDS 500 Hz 'up'. After all, a nominal frequency of 12 kHz must be maintained at the output of the receiver. The slightly shifted IF will easily fit in the bandpass of the IF filter, allowing us to omit an expensive second oscillator and design one around a cheap ceramic resonator type CSB470. Due to the large capacitance presented by the oscillator (C15 and C16), the resonator is pulled down 3 kHz with a tolerance of about 1 kHz.

The IF signal is raised by about 20 dB by a single transistor stage (T2). Overdriving is unlikely to occur because the signal levels are relatively small due to the slight attenuation by the IF filter and the absence of prestage or mixer gain.

JFET T4 operates as a passive mixer, that is, a switch for RF signals, being opened and closed by the 467-kHz local oscillator signal. Besides utter simplicity, the main advantage of a passive FET mixer is its large dynamic range — signal levels up to 100 mV are handled without problems.

DDS tuning

The DDS VFO based on an AD9835 from Analog Devices is controlled almost directly from the PC's serial port. An MC1489 RS232 receiver chip (IC1) takes care of the swing conversion. Although the DDS clock signal of 50 MHz would allow a highest receiver fre-

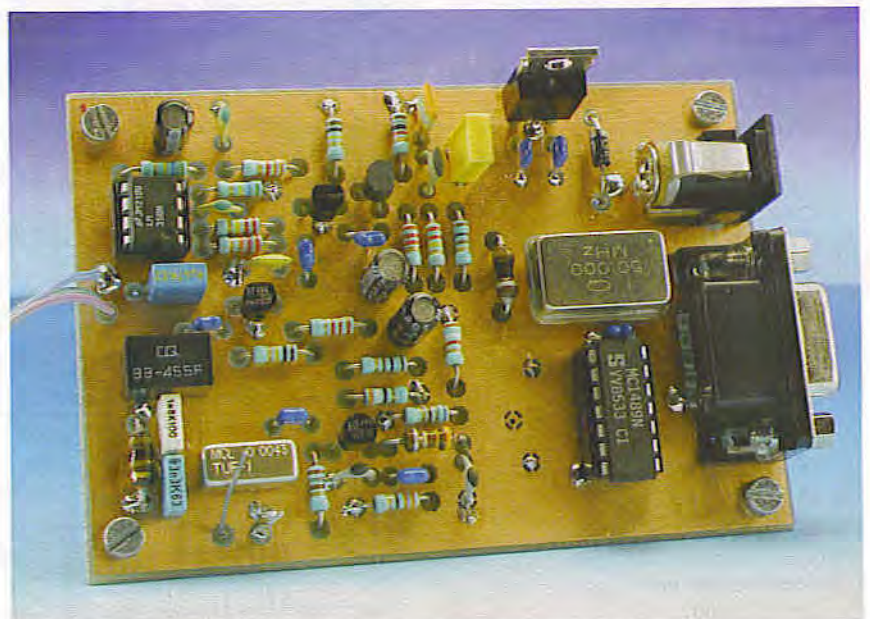
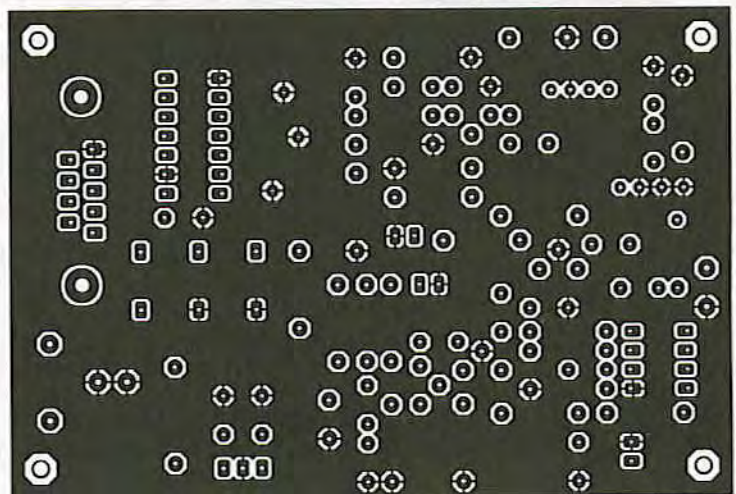
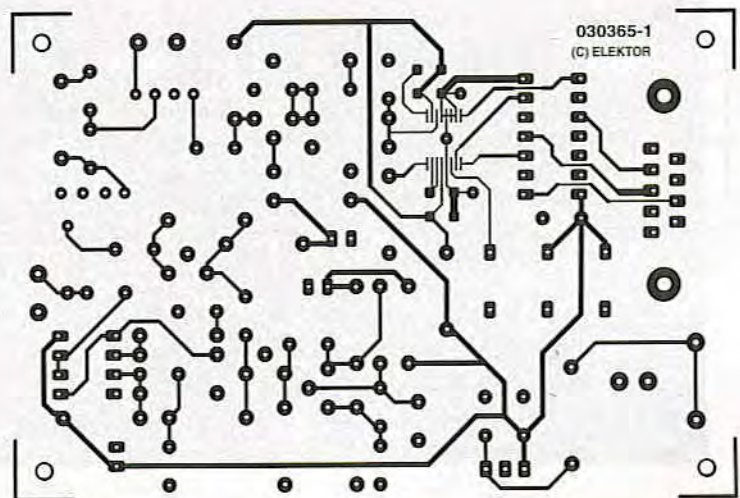


Figure 4. Component mounting plan of the board tested and approved by the Elektor design laboratory. The large copper plane allows short ground connections.

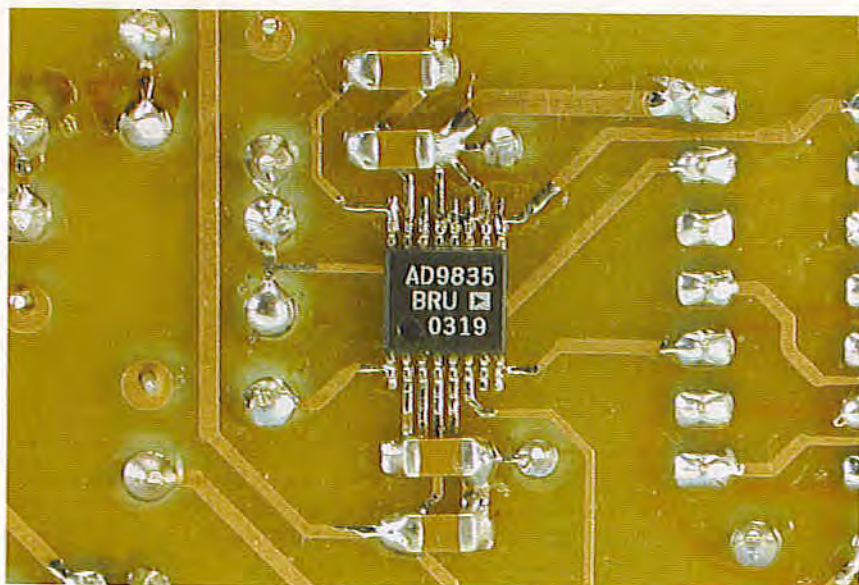


Figure 5. The DDS IC (only available in an SMD case) is soldered to the underside of the board, together with four SMD capacitors.

quency of 25 MHz, the output signals near this frequency become too weak and 24 MHz should be regarded as the absolute limit. A simple low-pass filter (C5, L1, C6) with a roll-off at about 24 MHz provides sufficient rejection of harmonics. Likewise, an additional amplifier, T1, ensures sufficient LO drive for the mixer.

Analog Devices offers a wide range of DDS integrated circuits including a few with a higher clock frequency. The AD9835 was chosen

for its relatively low cost and easy availability (Segor Electronics, Geist Electronics, Barend Hendriksen). The low intermediate frequency of 455 kHz causes a VFO frequency that's only a little above the received signal. The upper limit of the VFO frequency range is not sharply defined — the VFO output level will simply drop gradually above 20 MHz or so. As an aside, this allowed us to receive the Deutsche Welle DRM broadcast from Trincomalee, Sri Lanka, without too much of an effort.

Step-by-step

The following sequence is suggested when connecting the receiver to a PC.

1. Connect the 1:1 RS232 cable to the PC and the receiver.
2. Connect the receiver output to the Line input of your soundcard by means of a screened audio cable.
3. Switch on the receiver.
4. Launch the DRM software on the PC; select soundcard as target and source.
5. Double-click on the loudspeaker symbol in the right-hand bottom corner of the Windows desktop (or via Programs – Accessories – Entertainment – Volume Control) to open the volume control window (the one with the slide controls).
6. Select Properties, then Options and check the box Adjust volume for: **Recording**.
7. Check the box for the soundcard input you want to use (Line or Microphone) and click OK.
8. In the window that pops up, adjust the volume of the desired input.
9. Return to Options – Properties and now select **Playback**. Disable all inputs (remove the check mark) except for the one you're using for the receiver (normally **Wave**). Use the two slide controls at the left-hand side to control the volume on the PC loudspeakers.
10. Launch DRM.exe to tune the receiver to a DRM station.

The receiver is tuned by a program called DRM.exe, which makes provision for the receiver calibration. The inset 'Step-by-Step' tells you how to start using the receiver. When DRM.exe is first started, it needs to be told which COM port you want to use. The program default is COM1 which may be changed into COM2, for example. By clicking on 'Save Setup' the COM port selection is saved in a file called 'init.txt', along with a few other salient parameters for easy retrieval the next time the program is used. As soon as the serial connection is successfully established, the slider (at the top in Figure 6) may be used to tune the receiver with 1-kHz resolution. The arrows at the edges cause 1-kHz steps, a click in the areas beside the slider, a step of 10 kHz.

Calibration

Frequency calibration is required because the two local oscillators in the receiver are subject to a certain tolerance for which no hardware adjustments are available. First, the software needs to know the exact frequency of the 467-kHz oscillator. Adjust the receiver frequency to 0.00 (slider to leftmost position) and start the DRM software. (Note: in the following description it is assumed that the program 'DRM Software Radio' from Fraunhofer IIS is used — however, it is also possible to employ 'Dream' (see 'Decoder Software' inset). No antenna should be connected at this point. The spectrum (Figure 7) will show a straight line caused by the first oscillator being tuned to the intermediate frequency. (Note: if the receiver were switched on after

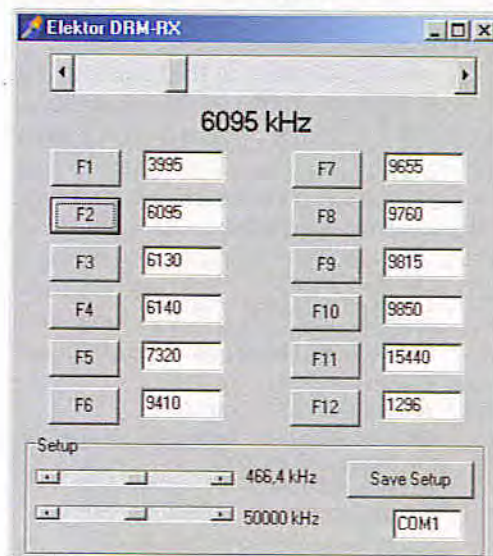


Figure 6. Windows program DRM.exe for the receiver tuning in action.

launching the software, the line does not become visible after you've moved the slider a little. If the line still does not appear, the receiver's output signal may be too small for the Line input — change to the microphone input and try again. Receiver noise should be just visible in the lower part of the screen. Possibly, the line falls outside the screen area — adjust the slider until the line appears). Next, the upper slider in the Setup Range has to be adjusted for the line to appear exactly in the centre of the spectrum. If that is achieved, the

Listing 1

VB code snippets

```
Const XTAL = 40000
Const IF1 = 454.3

Private Sub output(Data)
    TXD 0
    Delay 0.1
    DTR 1          ' CE
    Delay 0.1
    BitValue = &H8000&
    For n = 0 To 15
        If (Data And BitValue) >
            0 Then RTS 0 Else RTS 1
            Delay 0.1
            TXD 1          ' clock
            Delay 0.1
            TXD 0
            Delay 0.1
            Delay 0.1
            BitValue = BitValue \ 2
    Next n
    Delay 0.1
    DTR 0
    Delay 0.1
End Sub

Private Sub LO(freq)
    HScroll1.Value = freq
    Labell.Caption =
        Str$(freq) + " kHz"
    Dim frg As Long
    Dim freqLo As Long
    Dim freqHi As Long
    Dim Daten As Long
    freq=freq+IF1 'add IF1
    frg=Int(freq/XTAL*
        4294967296#)
    freqHi=frg\&H10000
    freqLo=frg-freqHi*&H10000
    freqLoL=freqLo And &HFF
    freqLoH=freqLo\&H100
    freqHiL=freqHi And &HFF
    freqHiH=freqHi \ &H100
    output &HF800& 'Reset
    '4 Bytes to FREQ0
    output(&H3000& + freqLoL)
    output(&H2100& + freqLoH)
    output(&H3200& + freqHiL)
    output(&H2300& + freqHiH)
    output &H8000& 'Sync
    output &HC000& 'Reset end
End Sub
```

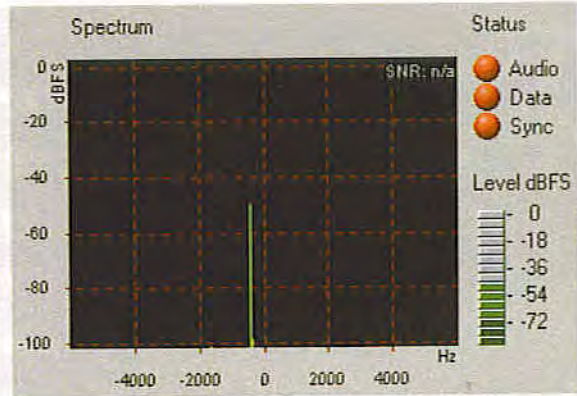


Figure 7. Illustrating IF calibration, here using the program DRM Software Radio (v. 2.034).

receiver supplies an output signal of exactly 12 kHz. On our prototype, the setting was found to correspond to a frequency of 466.4 kHz from which we can conclude that the second oscillator had an error of 600 Hz. This error, then, is compensated by the software offsetting the DDS oscillator by the same amount. The adjustment range of the calibration is ± 2 kHz.

The second step is to eliminate the error in the DDS clock oscillator frequency. The 50.000-MHz quartz crystal oscillator has a basic tolerance of ± 100 ppm or 100 Hz per MHz, so that a final error of up to 5kHz may occur at 50 MHz. Consequently, the error would be 1 kHz for a receive frequency of 10 MHz. The calibration begins by connecting the antenna to the receiver input and tuning to a strong AM station in the shortwave range (tune using the top slider in DRM.exe). The vast majority of SW broadcast stations can be used as frequency standards, their

station frequencies complying with high stability standards and a 5-kHz raster. **Figure 8** shows the spectrum of an AM transmitter at 6805 kHz. The lower slider has to be adjusted for the carrier to occur exactly in the centre.

Theoretically, at this point you would have to repeat the first calibration step, then the second and so on. In practice, that is not necessary because the small error in the clock oscillator frequency amounts to no more than 1% in the IF range. With an error of 1 kHz at 50 MHz established, the error at 455 kHz is an insignificant 10 Hz. The DRM software we propose to use requires an absolute accuracy of 'just' ± 500 Hz.

When you are done calibrating the oscillators, do not forget to save the setup data to make them quickly available again the next time the receiver is switched on. By the way, more data is saved, including the current station frequency. Station buttons may be linked to your pre-

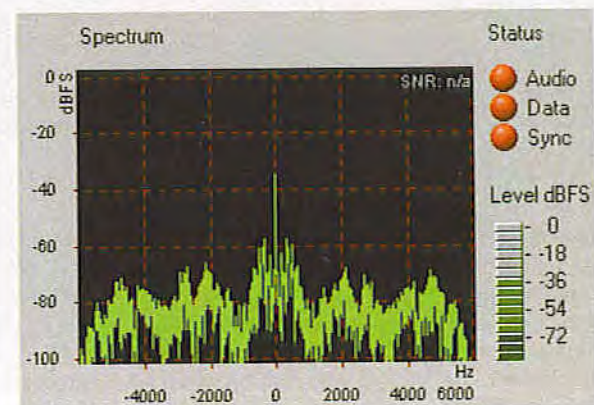


Figure 8. Using an AM broadcast station carrier as a frequency reference.

Decoder software

In addition to the tuning program DRM.exe (supplied by Elektor on disk or as a Free Download) you will require DRM demodulation/decoding software that works in combination with your PC soundcard. Two products are available on the market.

DRM Software Radio produced by the German Fraunhofer IIS (currently version 2.034) may be obtained at a cost of 60 Euros (approx. £43) from an online shop facility at www.drmtx.org. Payment for your order is by credit card. The download information and a software key arrive by email. The latest version supports the new MP4-based DRM standard introduced on 15 December 2003. Nearly all DRM stations now broadcast in stereo and achieve excellent sound quality using the new format.

The **DREAM** open-source project from Volkert Fischer and Alexander Kurpiers (a former Elektor author) of the Darmstadt University Institute for Communications Technology is currently available as version 1.0. The program is only supplied in the form of a C++ source code file because the authors have employed third-party modules that have to be obtained from the respective owners. The DREAM code itself may be found at

<http://sourceforge.net/projects/drm/>

The project may be compiled for Windows as well as Linux. If you are less than conversant with a C++ compiler, ask around for assistance with the creation of the files. DREAM_V1.0 has evolved into a serious alternative to the DRM Software Radio package. The program is stable and now presents less of a CPU load than before.

Meanwhile, the reception of pictures has become possible and the program is also capable of writing a log file containing reception reports. DREAM is very tolerant in respect of the exact frequency of the DRM baseband and will faithfully scan the complete range from 0 to 24 kHz. AM reception has been added as an extra mode, allowing the DRM receiver to be used for classic broadcast reception on the long- medium and shortwave bands.

In a future issue we will return to the DRM software decoder in greater detail. The DRM programs mentioned above are compatible with Windows 98 and up (i.e., 98, 2000, NT and XP).

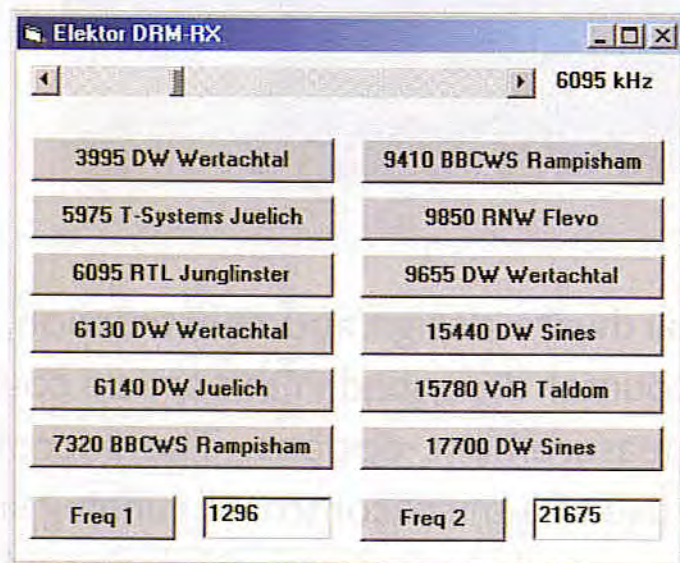


Figure 9. GUI produced by the Visual BASIC example program written for the receiver tuning and station preselect functions.

ferred frequencies and they to are saved in the setup file. The file is editable using a word processor. So, if you (against sound advice) decide to overclock your DDS at 60 MHz, the new frequencies may be entered here.

Control using Visual BASIC

The PC-controlled tuning of the DRM receiver opens a lot of potential, including, for instance, labelled preselect buttons for your favourite stations, or timer-driven tuning to certain scheduled broadcasts. Moreover, the DDS may be used for measurement purposes. To give all readers maximum freedom in further experiments, the DDS control is explained here using a small example. The user interface produced by the example program is shown in **Figure 9**. The program employs one slider control, quick tuning buttons and two boxes for free tuning. Calibration facilities are not provided for the end user, the calibration being performed by constants hidden in the program.

The two decisive procedures of the program are shown in **Listing 1**. Using output (Data), 16 bits are shifted into a register inside the AD9835. The procedure LO computes the frequency and the required register contents of the DDS component. The output frequency is adjusted through a 32-bit value, the step size being $50 \text{ MHz}/2^{32} = 0.01164 \text{ MHz}$. The allocation of these registers and their addressing in the upper part of the 16-bit control word is detailed in the AD9835 datasheet. The program example shows the seven essential register contents needed to actually set the DDS frequency. A frequency 'word' is divided into four bytes conveyed to four partial registers.

Near the top of the source code you'll find two constants that have to be adapted to enable the frequency to be calibrated. The necessary data are taken from the ready-made user program for the receiver. XTAL = 50000 stands for the exact clock oscillator frequency, while IF1 = 455 defines the intermediate frequency. At a frequency of 466.3 kHz the IF becomes $466.3 \text{ kHz} - 12 \text{ kHz} = 454.3 \text{ kHz}$. The software controlling the RS232 traffic is a BAS module already described in [3].

(030365-1)

For further reading:

- [1] 'Digital Radio Mondial', Elektor Electronics December 2002.
- [2] 'An Experimental DRM Receiver', Elektor Electronics December 2003
- [3] PC Serial Peripheral Design, parts 1-7, Elektor Electronics September 2000 – March 2001