A NAVTEX Receiver for the DXer

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Introduction

NAVTEX is the primary means for transmitting coastal urgent marine safety information to ships world wide. All NAVTEX broadcasts are made on 518 kHz, using 7-unit forward error correcting (FEC) transmission. This type of transmission, usually referred to as SITOR-B, is also known among radio amateurs as AMTOR FEC mode. Broadcasts use 100 baud FSK modulation, with a frequency shift of 170 Hz [1, 2]. Urgent messages are transmitted immediately; routine broadcasts are sent every four hours.

Recently several authorities have announced to implement additional broadcasts in their national languages on 490 kHz. The British and French NAVTEX stations are already on this frequency.

For the shortwave listener it can be quite interesting to monitor NAVTEX broadcasts. This is possible with an amateur radio receiver or a communications receiver and a suitable decoder. But it is also nice to have a dedicated NAVTEX receiver. The construction of such a receiver is described here. A word of caution: Please do not expect a perfect kit; this is more a “report from the laboratory desk”.

Principles of operation

The receiver is a direct conversion (D-C) image-cancelling receiver. The RF input signal is converted to a centre frequency of 400 Hz. The image frequency (f_{in} + or - 2 x f_{out}, where f_{out} = 400 Hz) is rejected by applying the SSB phase method [3, 4]. The receiver is designed as a pure FM system with limiting amplifiers and has no automatic gain control (fig. 1). It can operate on both 518 and 490 kHz. Unlike commercial NAVTEX receivers for shipping, it does not feature a direct printout on paper, but sends out the decoded data over a serial port. Virtually any terminal program (e.g. Windows 95/98 Hypertrm.exe) can be used to view the messages and save them to disk.

An image-rejecting receiver is more complex than a conventional D-C receiver. It requires two mixers instead of one and carefully adjusted phase shifters. The circuit can be simplified, however, if we assume that there are no stations transmitting on adjacent channels, i.e. in the range 518 ± 1 kHz or 490 ± 1 kHz. This is usually the case. Remaining wide-band interference, like atmospheric noise or sparks from electric engines, has the same power density on both the desired and the image frequency. In this case, an image attenuation of only 10 dB is sufficient to obtain the same signal-to-noise ratio as with a conventional radio with crystal filter. This can be achieved with a relatively simple circuit without adjustment.

An improvement of (only) 3 dB, which is gained by cancelling the image noise, is perhaps not worth the effort of the additional circuitry (3 operational amplifiers plus passive components, 2 D-flip-flops in the oscillator), but the main reason for this construction was to study the principle in a digital data receiver. However, when dealing with weak distant stations, the 3 dB improvement may often lift a signal just above the readability threshold. Of course we have to be careful not to bargain it away by making the receiver filters too wide.

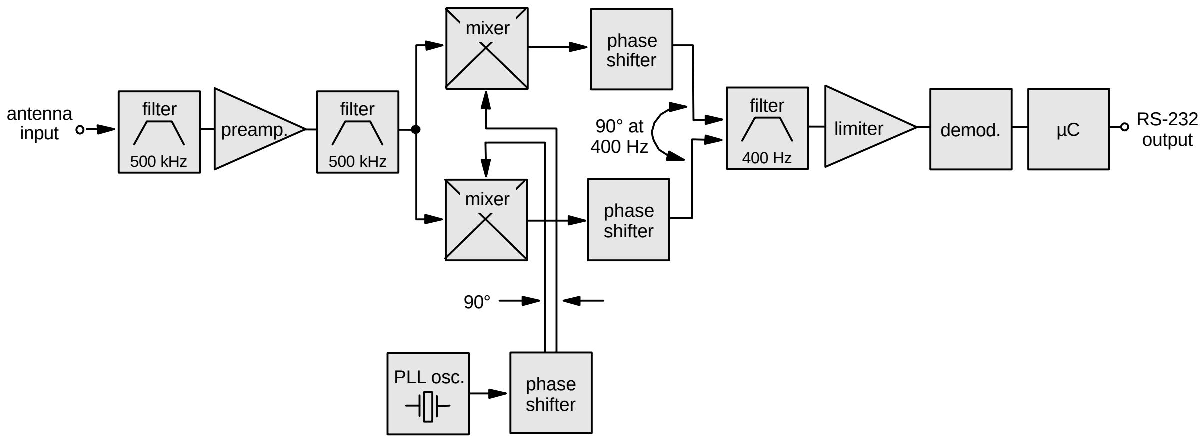


Fig. 1. Block diagram of the homemade NAVTEX receiver.

Mixers, filters, demodulator

The receiver is designed for an antenna with an impedance of 50 ohms, usually an active system. The input L network has a bandwidth of about 70 kHz. The preamplifier (T1, see fig. 3) is followed by a Pi filter, made of two L networks connected back-to-back [3], with an arbitrary chosen centre impedance of 22 ohms and Q factors of 8 and 7, respectively[1].

CMOS switches (U1c, U1d) are used as mixers. The signal of either mixer output is amplified (U2a, U2b) and fed into a first-order all pass filter (U2c, U2d), specified for 90° phase shift at 950 Hz (U2c) and 160 Hz (U2d). This yields a phase difference of 90° around 400 Hz between the outputs of U2c and U2d. Corresponding resistors in the upper and lower branch were paired to within 1% and capacitors to about 3%, but this selection is not really necessary.

U2a and U2b are not just amplifiers, but also the first stage of a 5th-order Butterworth lowpass filter. The main part of this filter with a cut-off frequency of approximately 580 Hz is built around U3a and U3b. The lowpass output signal is fed into a 2nd-order highpass filter (U3c, $f_c \approx 200$ Hz). The overall filter characteristic is shown

[1] For the component values shown (1800 pF / 100 µH / 2200 pF). A slightly increased selectivity can be obtained with 3900 pF / 47 µH / 4700 pF.

in figure 2. U3d amplifies the signal by a factor 100; strong signals are clipped in this stage. The final limiting amplifier is built of unbuffered CMOS inverters (U5a-d).

An audio amplifier (U4) has been added to be able to judge the signal quality by ear. The sound is somewhat “fuzzy”, particularly at levels where U3d just starts to clip; a first-order low pass has been added to make it less annoyant. On the other hand, the limiting property of U3d prevents the audio output from getting too loud in case of strong impulses like atmospheric noise.

The demodulator is of the frequency-to-voltage converter type. A simple monoflop-like circuit (U5e, U5f) triggers on both rising and falling edges. Its output pulses, now with an average rate of 800 Hz, are fed to a 4th-order lowpass filter (U6c, U6d, $f_c \approx 70$ Hz, Bessel filter characteristic). The DC voltage at the output of U6d is a measure for the receivers’s input frequency. A trigger circuit with floating threshold (U6b) “decides” whether the received signal is a logical 0 or a 1.

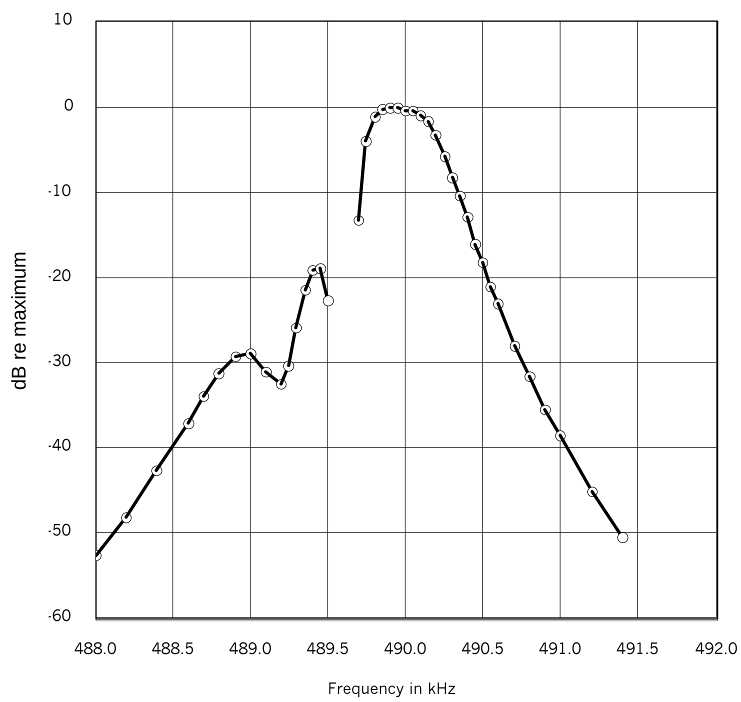


Fig. 2. Measured filter response. No data was taken close to the oscillator frequency at 489.6 kHz. Note the dip on the image frequency 489.2 kHz. A common direct-conversion receiver without image cancelling would show the same response here as on 490 kHz.

Oscillator

In spite of the rule that an RC oscillator is unsuitable as a receiver oscillator due to its low Q and excessive phase noise, the circuit in fig. 4 makes use of the PLL IC’s built-in VCO. A relatively high reference frequency of 115.2 kHz and the fact that the VCO frequency is divided by 4 makes the noise acceptable. The loop filter is extremely simple. The noise characteristics can be adjusted with two trim potenti-ometers between “noisy, but low discrete sidebands” and “less noisy, but stronger discrete lines”.

The effect of oscillator noise is an increase of noise in the receiver and hence a loss of sensitivity due to “reciprocal mixing” [5]. The medium-wave broadcast band is too far off to cause noticeable reciprocal mixing, but it may become a problem if there are strong stations adjacent to the NAVTEX channels, military stations for example.

The 90° phase shift is carried out with two D-flip-flops (74HC74); in the process the VCO frequency is divided by 4. Oscillator frequencies fed to the mixers are 489.6 kHz (17 x 28.8 kHz) and 518.4 kHz (18 x 28.8 kHz). Since the oscillator operates below the input frequency at 490 kHz and above the input frequency at 518 kHz, the phase shift has to be reversed when switching between the two frequencies. Otherwise the image cancelling mechanism would reject the wrong sideband. For this reason an exclusive-or gate (1/4 x 74HC86) acts as a switchable inverter on one of the two oscillator outputs.

On 518 kHz, the lower sideband is received, but the upper sideband 490 kHz. This makes it necessary to invert the data polarity for one of the two channels. This is done by the microcontroller; but of course one of the remaining 74HC86 ex-or gates could have been used for this purpose as well.

Microcontroller

An Atmel AT89C2051 (fig. 5) performs the following tasks:

- bit synchronisation,
- decoding the SITOR-B data stream and ASCII output via RS-232 line,
- adding a time stamp,
- driving status LEDs.

Data synchronisation on the bit level is performed by means of a 100 Hz software oscillator, which can be phase-adjusted in steps of 312.5 µs. For this purpose, timer 0 of the ’51 is running in the auto-reload mode, with an interrupt rate of 3200 Hz. On falling slopes in the raw data, a correction step shifts the centre of the 10 ms oscillator period towards the data edge. Not every falling slope is examined; the rate is adjustable. As soon as the receiver has detected a SITOR-B phasing sequence, the updates are made at a less frequent rate.

Commercial NAVTEX equipment can be programmed to respond to messages from a particular station only; furthermore certain message types can be suppressed. These features are not included here. Anything that is decoded is printed on the screen. The output rate is fixed at 9600 Baud.

The receiver has a time stamp function, which is useful for unattended monitoring. If activated, the actual time is printed in hhmm format at the beginning of each line. The clock does not yet have a battery backup. It is planned to include a Dallas DS1302 real-time clock in a future version of the receiver.

Construction

Each of three subassemblies receiver, oscillator and microcontroller was built on cheap perforated board with strip-line copper cladding (fig. 6). The relatively large aluminium enclosure makes tests and modifications easier, but a more compact construction is certainly possible. Overall material costs were not calculated; the cabinet was by far the most expensive part (about 35 DEM). According to the mid 2000 price list of a German electronics supplier (Reichelt Elektronik, 26452 Sande, www.reichelt.de), all semiconductors including the controller cost less than 20 DEM (< 10 US$, < 10 Euro).

Practical experiences

In the first tests with an active rod antenna (Rhode & Schwarz HE-011), the receiver performance was found to be surprisingly good. A couple of overnight logs to disk revealed more than 30 stations from all over Europe, as well as a few stations from Canada and the Near East.

A Wellbrook ALA 1530 wideband active loop antenna, however, caused occasional AM breakthrough at nighttime, a common problem with D-C receivers. It is not yet clear if this is simply induced by the higher output level of the ALA 1530, or if some other problem is pending. Probably it can be cured by replacing the input circuit with high Q filters that are switched between 490 and 518 kHz.

A few sample logs are shown in figs. 7 and 8.

References

[1] International Telecommunication Union: Recommendation ITU-R M.476-5. Direct-printing telegraph equipment in the maritime mobile service. Geneva 1995 (first published in 1970, now superseded by ITU-R M.625-3)

[2] US Coast Guard Navigation Center: http://www.navcen.uscg.mil/marcomms/

[3] Jon B. Hagen: Radio-Frequency Electronics. Cambridge University Press 1996

[4] William E. Sabin, W0IYH: Receivers, Transmitters, Transceivers and Projects. In: The ARRL Handbook 1998. The American Radio Relay League, Newington, CT 1997

[5] David Stockton, GM4ZNX: AC/RF Sources. In: The ARRL Handbook 1998. The American Radio Relay League, Newington, CT 1997

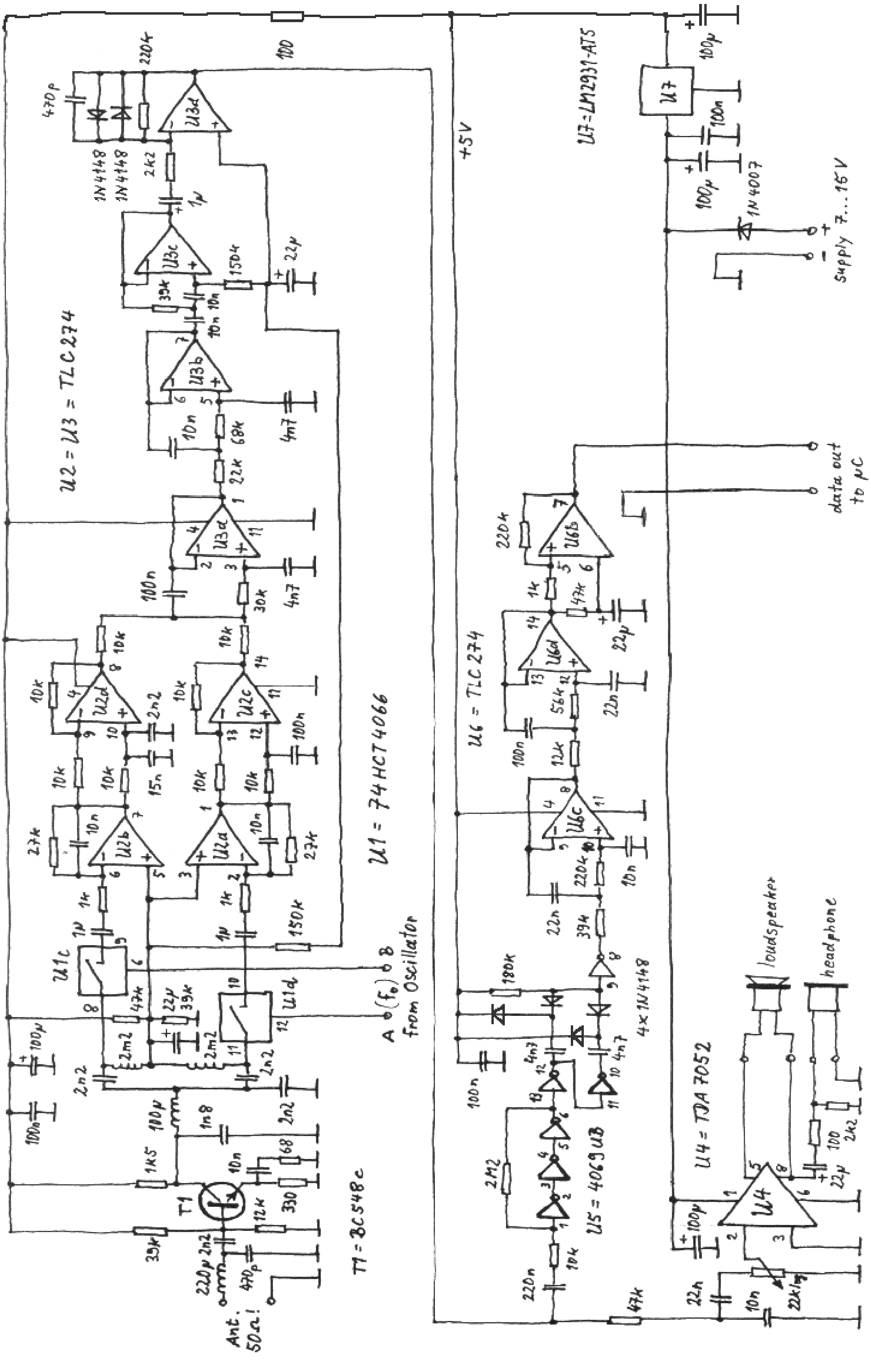


Fig. 3. Schematic diagram of the main receiver section.

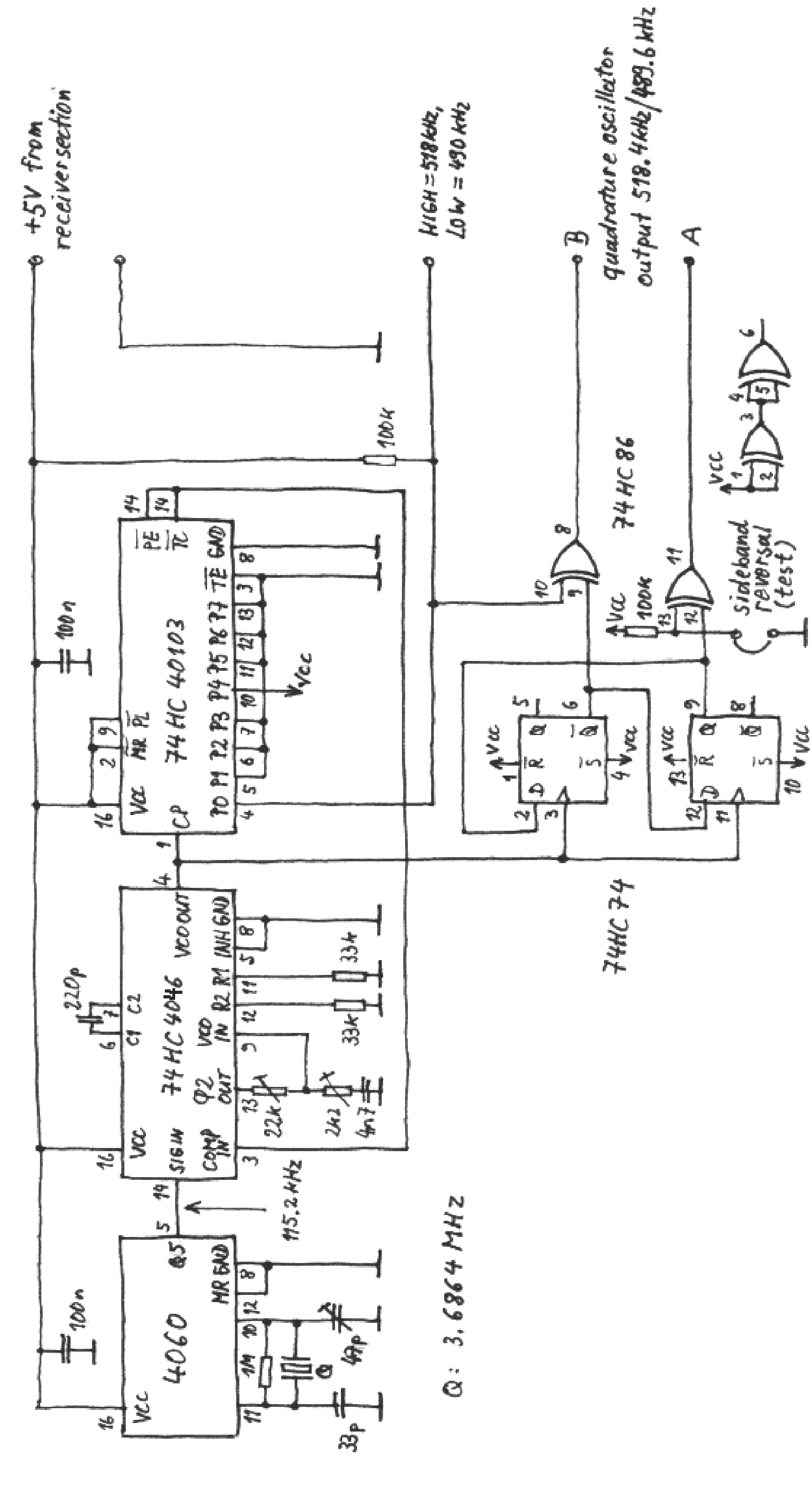


Fig. 4. Oscillator schematic.

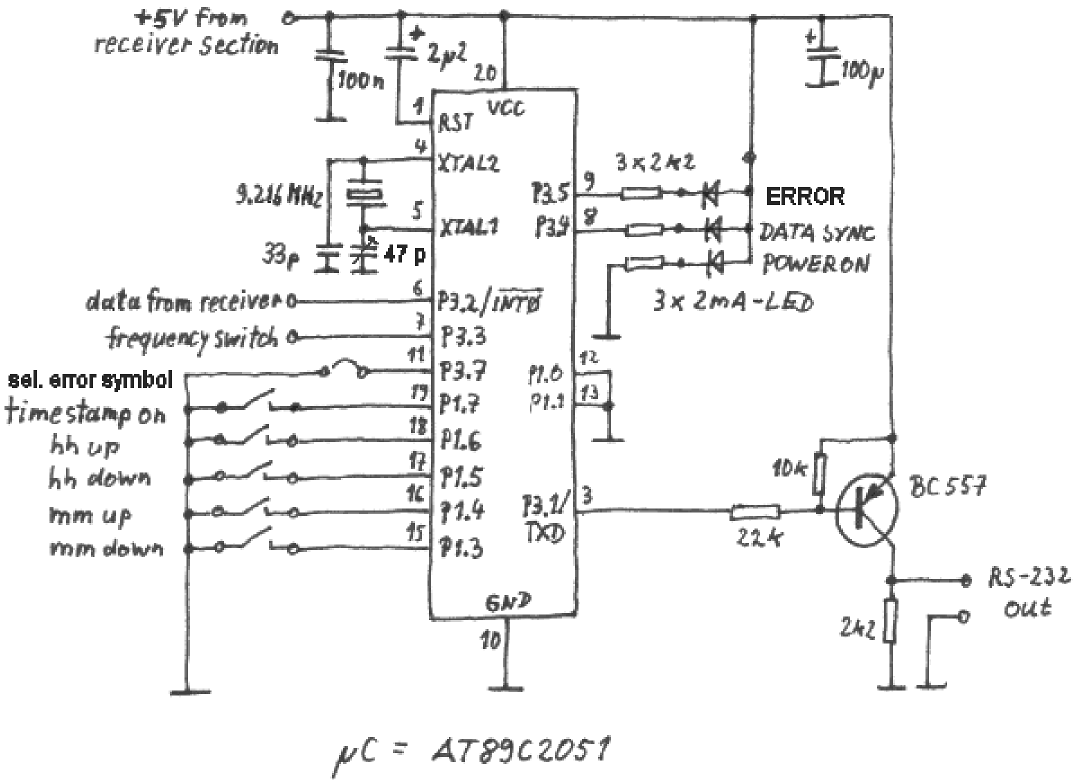


Fig. 5. Circuit diagram of the microcontroller subassembly. The RS-232 output is soldered to pin 2 of a common female 9-pin connector; ground to pin 5. The remote computer is connected via an 1:1 extension cable (not a null modem with crossed lines).

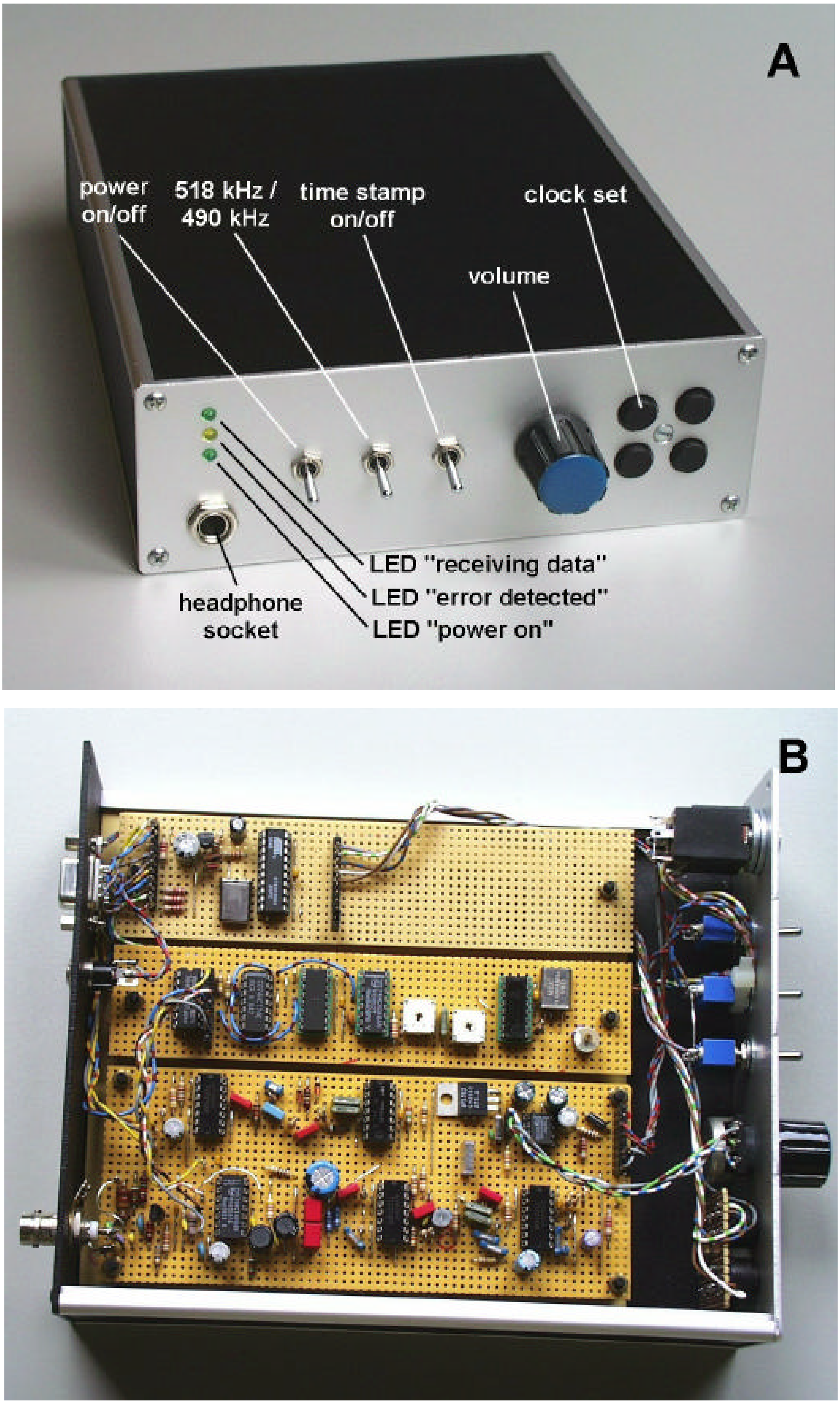
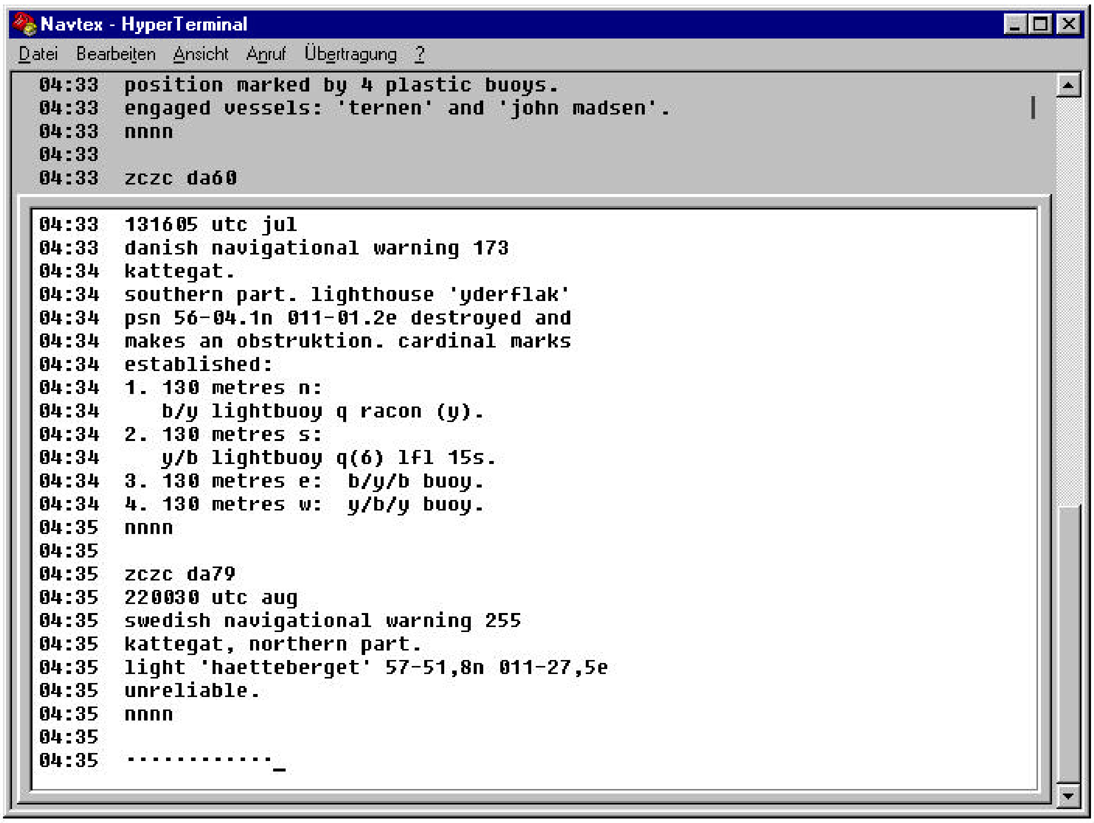


Fig. 6. Prototype assembly. A: front panel, B: interior (bottom cover removed).



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Navtex - HyperTerminal
Datei Bearbeiten Ansicht Anruf Übertragung ?
04:33  position marked by 4 plastic buoys.
04:33  engaged vessels: 'ternen' and 'john madsen'.
04:33  nnnn
04:33
04:33  zczc da60
04:33  131605 utc jul
04:33  danish navigational warning 173
04:34  kattegat.
04:34  southern part. lighthouse 'yderflak'
04:34  psn 56-04.1n 011-01.2e destroyed and
04:34  makes an obstruktion. cardinal marks
04:34  established:
04:34  1. 130 metres n:
04:34     b/y lightbuoy q racon (y).
04:34  2. 130 metres s:
04:34     y/b lightbuoy q(6) lfl 15s.
04:34  3. 130 metres e:  b/y/b buoy.
04:34  4. 130 metres w:  y/b/y buoy.
04:35  nnnn
04:35
04:35  zczc da79
04:35  220030 utc aug
04:35  swedish navigational warning 255
04:35  kattegat, northern part.
04:35  light 'haetteberget' 57-51,8n 011-27,5e
04:35  unreliable.
04:35  nnnn
04:35
04:35  ............_
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Fig. 7. Screenshot of NAVTEX log in a terminal window, with time stamp function on.

```
zczc xz41
greenland 010212 2355 utc
no message on hand

nnnn




zczc rx68
reykjavikradio 010212 0250 utc
vegna framkvaemda vid nausthamars-
bryggju i vestmannaeyjum ma buast
vid ad leidarljos er leida inn i
hoefnina verdi ovirk af og til a
timabilinu fra 12.feb. til 1. sept 2001.
siglingastofnun islands
nnnn
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Fig. 8. Two messages from Reykjavik Radio, the latter one in Icelandic.