1.2Mbit/s SuperVozelj packet-radio node system

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On 12/6/1995, we (S53SM, S59AW, S57MSL and S53MV) upgraded our first SuperVozelj packet-radio node GORICA:S55YNG (see Fig. 1) with one port operating at 1.2288Mbit/s with a PSK transceiver operating on 2360MHz. The new high-speed node is currently linked at 1.2288Mbit/s only to the experimental SuperVozelj node RAFUT:S59DAY installed at my QTH (S53MV). Since the new node is certainly the fastest AX.25 amateur-radio packet node in Slovenia and I believe probably one of the fastest packet-radio nodes in Europe, I hope that the following description of our packet-radio node system SuperVozelj will be of interest to many radio amateurs.

1. Short history of the SuperVozelj project

The development of faster packet radio links started in Slovenia already in 1988, when it was clear that 1200bit/s AFSK Bell-202 links can not cope with the amount of both local and international traffic crossing our country. In 1989 we installed the first links operating in the 23cm amateur-radio band using wide band (250kHz) FM transceivers and simple Manchester modems at an operating speed of 38.4kbit/s.

At that time the only known choice for node computers was the TNC2 running NETROM or TheNet software. In the following years the network of 38.4kbit/s nodes was extended to cover the whole Slovenia and a few links to some neighboring countries were also installed. As the network was growing, it soon became apparent that the TNC2 and in particular the software was not able to cope with the traffic at 38.4kbit/s. The TheNet software was crashing at an increasing rate while new versions of this software only included new bugs, with none of old, well known bugs ever being removed.

Therefore a replacement was sought for the obsolete TNC2 and the poorly written NETROM/TheNet software. Since we could not find any replacement that could offer something more than what we already had, in 1992 I started developing our own network node computer named SuperVozelj. SuperVozelj is based on the MC68010 CPU and Z8530 SCC chips. At the end of 1992 we already installed the first operational SuperVozelj node offering six interrupt-serviced channels for operating speeds up to 76.8kbit/s per channel.

Since the SuperVozelj node computer offered a great improvement of the network capacity compared to TNC2/TneNet using the same modems and transceivers, it also made sense to upgrade the user equipment from 1200bit/s Bell-202 or 2400bit/s Manchester to higher operating speeds. In 1993 I developed and tested simple wide band (250kHz) FM transceivers for the 70cm amateur band. In 1994 several packet-radio nodes were upgraded to have a 19.2kbit/s, 38.4kbit/s or even 76.8kbit/s user access in the

70cm band. Since 70cm WBFM radios are cheap and easy to build, several users followed the upgrade of the network and today the majority of active packet-radio users in Slovenia operate at 19.2kbit/s or faster.

User upgrades soon caused the congestion of the 38.4kbit/s interlinks on both 70cm and 23cm. The move to even higher speeds requires using even higher carrier frequencies with wider bandwidths. At higher frequencies the available TX power is getting lower, so more power-efficient modulation techniques need to be used. My current choice is to use the 2.3GHz amateur band with PSK modulation at 1.2288Mbit/s. PSK modulation allows at 1.2Mbit/s a similar radio range as WBFM radios with Manchester modems at 38.4kbit/s, in other words about 100km free space range with 20dB link margin and moderate-size antennas (15-20dBi), as required for typical amateur-quality packet-radio links.

The development of suitable 2360MHz PSK transceivers started already at the end of 1993. The first operating transceivers were built in the beginning of 1995, followed by the development of a DMA-SCC interface card and relative software for the SuperVozelj node computer. In the beginning of May 1995 the first QSO was made on 2360MHz, 1.2288Mbit/s at a distance of only a few meters in my lab at home. On 12/6/1995 we installed the first operational node GORICA:S55YNG and the first 1.2288Mbit/s QSO was made on a real distance (6km) using 16dBi antennas. 6km may not seem a large distance, but there is no optical visibility between the antennas of the two nodes S55YNG and S59DAY linked at 1.2288Mbit/s, the obstacle in between (hill) being larger than the 10th Fresnel zone at a wavelength of 13cm. This simply means that 1.2288Mbit/s packet radio will not be limited to line-of-sight propagation of radio waves if reasonably designed equipment is being used.

2. SuperVozelj packet-radio node computer

A packet-radio node computer is usually installed on a remote site that is not easily accessible, generally a mountain top. Therefore the node computer has to be very reliable and for this reason the use of IBM PC based hardware and/or software has to be STRICTLY AVOIDED. For SuperVozelj I decided to use some modules of my own computer design based on the Motorola MC68010 16-bit microprocessor. The latter design includes a bus with "eurocard" connectors, nonvolatile CMOS RAMs, a real-time clock and a parallel port (see Fig. 2).

The Z8530 SCC chip was chosen as the serial interface mainly because of its easy availability and relative completeness, since it includes a DPLL for RX clock recovery and can generate both interrupts and DMA requests. On the other hand the Z8530 chip has several hardware bugs that the manual calls "features" when operating in the HDLC X.25 mode and the bus interface is only 8 bits wide. A final advantage of the Z8530 is that its bugs are well known since the chip is widely used.

Right at the beginning I decided to write the SuperVozelj software entirely in 68k assembly language. The Motorola 68k assembler offers enough instructions that it is really not necessary nor convenient to use a higher-level language compiler for the described application. Writing the whole software in assembly language also means to have a full access to the machine code, which is of utmost importance when writing time-critical applications like a packet-radio node computer. Thinking about future hardware upgrades, the 68k assembler is not a limitation, since all practical alternatives use either 68k microprocessors (MC68020 and follow-ons) or serial communication chips based on the 68k series (MC68302).

The first practical implementation of the SuperVozelj uses three Z8530 SCC chips generating interrupt requests directly to the MC68010 microprocessor without any DMA circuit. The operating speeds are limited by the interrupt-service routines to about 76.8kbit/s per channel or 200kbit/s for the whole SuperVozelj (12MHz CPU clock). In this case the internal baud-rate generators and DPLLs of the SCC chips can be used to significantly reduce the amount of additional hardware.

The most recent hardware upgrade is the DMA-SCC card that includes a 4-channel MC68450 DMA chip and a Z8530 SCC chip. The 4-channel DMA services independently the DMA requests of the two Z8530 receivers and two transmitters, allowing two full-duplex channels. The speed limit is set by the Z8530 chip to about 2Mbit/s per channel, but the speed limit of the 68k bus is also close to this value. At megabit-per-second speeds the internal baud-rate generators and DPLLs of the Z8530 chip can no longer be used and external clock sources and bit synchronization circuits are required.

Finally, the SuperVozelj node computer also includes a remote reset telecommand with a hardware sequence detector. The latter has never been used in the case of GORICA:S55YNG, since the SuperVozelj software NEVER CRASHED in two years and a half of continuous (battery-backed) operation. The remote reset circuit is therefore only used to correct for sysop mistakes, since the SuperVozelj system allows remote loading and testing of new software versions, stored conveniently in the nonvolatile CMOS RAM.

3. 1.2Mbit/s PSK link transceiver for 2360MHz

The choice of a transceiver design for high-speed packet is not simple. Is it better to use an apparently simpler FM transceiver or to go for a more sophisticated PSK transceiver? Both choices have their advantages and disadvantages and at this time it is difficult to predict which will become more practical. Personally I decided for PSK transceivers since there are more different designs available and more upgrades possible than with FM transceivers and the radio range is between 5dB and 15dB larger than with FM transceivers.

In packet radio the main problem of a PSK transceiver is the initial RX signal acquisition. The latter is a function of the carrier frequency uncertainty. In a simple biphase PSK system with 0/180 degrees modulation, the initial signal acquisition requires a complicated searching loop, if the frequency error exceeds 10% of the bit rate. Therefore PSK becomes simple if you go fast. On the other hand, making low-Earth orbit amateur satellites to run at only 1200bit/s makes the initial signal acquisition extremely difficult and this is perhaps the best known example of wrong PSK design.

Considering the 13cm amateur band, the sum of the frequency uncertainties of both receiver and transmitter is at least 10kHz using top quality temperature-compensated xtal oscillators. A real-world figure is 100kHz frequency uncertainty that requires a MINIMUM bit rate of about 1Mbit/s! With the above restriction a convenient choice is to use 1.2288Mbit/s. This figure can easily be obtained with standard baud-rate xtals, being the 32nd multiple of 38.4kbit/s or the 1024th multiple of 1200bit/s.

As already mentioned, a PSK tansceiver allows many different designs that have to be investigated. In my actual prototypes (see Fig. 3) I obtain direct PSK modulation of the transmitter in a balanced mixer operating at the final frequency 2.36GHz. The receiver uses double downconversion to 75MHz and then to 10MHz, where the PSK demodulation is performed. The microwave front-end for 2.36GHz uses relatively new SIEMENS semiconductors in SMD packages, originally developed for cellular telephones operating at 900MHz and 1.8GHz.

The transmitter includes a multiplier chain starting from a 18.4MHz fundamental resonance xtal. The same BFX89 oscillator transistor is used as a multiplier by 4 to obtain 73.7MHz. The multiplier chain then follows with another BFX89 (147.5MHz), yet another BFX89 (295MHz), a BFR91 (590MHz/+10dBm) and a BFR96 (1180MHz/+10dBm). The 1180MHz carrier is applied to a harmonic balanced mixer with a quad Schottky diode BAT14-099R that produces about -5dBm of PSK modulated signal at 2360MHz after the necessary filtering.

The PSK signal at 2360MHz is first amplified by a CFY30 to about +12dBm and then by a CLY2 to about +27dBm. The antenna switch uses a series PIN diode BAR63-03W and a shunt PIN diode BAR80. The receiver uses a CFY35 as the first RF amp, followed by a CFY30 in the second stage. The first downconversion is performed by a BAT14-099 double Schottky diode harmonic mixer, fed by a PLL synthesizer local oscillator producing 1147.5MHz.

The IF chain includes two amplifier stages at 75MHz (BFR90 and BF981), a second mixer to 10MHz (BF981) and an IF amplifier/ /limiter (CA3189). The PSK demodulator is a squaring-loop type demodulator. The main demodulator functions are performed by exclusive-OR gates (74HC86) used as mixers and frequency multipliers. The VCO uses two 2N2369 transistors and a 74F74 (dual D-flip-flop) frequency divider.

All of the RF modules of the 2.36GHz transceiver are placed in shielded boxes made of 0.5mm thick brass plate. The shape of these boxes is rather elongated (40mm width) to avoid internal resonances. There are in total 7 (seven) such shielding boxes in one transceiver, therefore the assembly of such a radio requires a lot of work and patience. The only unshielded module is the SuperVozelj interface. The digital signals are kept at TTL levels, but the inputs and outputs have 75-ohm terminations in the case the transceiver is installed close to the antenna to avoid microwave cable losses.

The 1.2288Mbit/s transceiver also requires an interface at the SuperVozelj side, interface that used to be called "modem" at lower bit rates. The interface includes 75-ohm drivers and receivers, a bit-synchronization DPLL and a scrambler/ /descrambler. The DPLL design is an interpolation DPLL that only requires a 8-times higher clock frequency (9.8304MHz) using conventional 74HCxxx logic, although provides the resolution of a /256 conventional DPLL with a 315MHz clock. The scrambler/descrambler was added for two reasons: to provide a smooth link degradation in the case of multi-path propagation and to drop the DC coupling requirement that complicates both FM and PSK transceiver designs.

4. User access WBFM transceivers for 70cm and 23cm

The original idea of the wideband FM transceiver is to have simple and cheap radios for fast packet-radio links. Wideband here means a bandwidth of 200-250kHz, since one can easily get ceramic filters for different center frequencies that all have the same above-mentioned bandwidth. The first WBFM radios for 23cm were put into service in Slovenia in 1989 together with simple Manchester modems operating at 38.4kbit/s (see Fig. 4).

Since our WBFM radios were installed before the K9NG/G3RUH modems became known to a wider audience, we never considered using K9NG/G3RUH FSK modems in our network. Our only experience with K9NG/G3RUH FSK modems is that they require very critical modifications to the audio and PLL circuits of expensive commercial transceivers and that the final result is uncertain even on the same transceiver model from the same manufacturer. Since the WBFM radios proved to be cheap and reliable, we never considered installing a more expensive system that is known to have inferior performances.

Encouraged with the success of the 23cm WBFM radios we tried to develop simple WBFM radios for user access in the 70cm band. Here one could argue that WBFM radios occupy too much precious bandwidth in the 70cm band. In practice we found that the opposite is true: WBFM radios with Manchester modems actually produce LESS INTERFERENCE to other users than NBFM radios with Bell-202 or G3RUH modems. The TX power of a WBFM radio is spread over a much wider bandwidth, so the power density is much lower. A WBFM radio will never open the squelch circuit of a NBFM voice transceiver, so FM voice users will seldom even notice the existance of a WBFM packet digipeater operating on the same frequency they are using for voice contacts. In other words, WBFM radios represent a simple form of spread-spectrum communications and spread-spectrum systems are usually proposed to limit mutual interferences.

Both 23cm and 70cm WBFM radios are similar in their basic design. Both radios have a PLL controlled TX with an output power between 1-2W and a receiver with a double downconversion to a final second IF frequency of 10.7MHz or 6MHz. The 23cm version is complicated because of the obsolete design, using some modules of a 23cm linear transverter. On the other hand, the 70cm version was made as simple as possible to be easily reproducible (two printed circuit boards of 60x120mm each, see Fig. 5).

Manchester coding is sometimes also referred as biphase coding. Each bit is split into two halves, the polarity of the second half being opposite to the first half. In this way the DC and low frequency components are eliminated, simplifying the interface of a Manchester modem to a FM transceiver. A Manchester modem can operate at up to 2400bit/s through an unmodified NBFM voice transceiver, at 4800bit/s through a NBFM transceiver modified for the G3RUH modem and at up to 76.8kbit/s through a cheap WBFM transceiver. A Manchester modem is very simple, about 10 pieces of 74HCxxx chips on a 75x100mm single-sided PCB including the DCD circuit and analog interfaces.

5. Plans for future upgrades

The above description only describes our first experiments at 1.2288Mbit/s. Although the described hardware is currently operating as expected, it still has several drawbacks. The SuperVozelj node computer itself is unable to handle the full capacity of two 1.2288Mbit/s channels. Therefore the CPU will have to be replaced with a MC68020 or an even faster microprocessor if the full channel capacity is to be used. The interface between the MC68450 and Z8530 and the Z8530 itself is not the best choice for speeds above 1Mbit/s. A MC68302 serial controller is a much better alternative.

The described PSK transceiver is both complicated and slow, requiring a TX delay of 2-3ms. This is fairly excessive at 1.2288Mbit/s. This delay is mainly caused by the turn-on transient of the transmitter oscillator. PSK reception also allows a direct-conversion receiver just like SSB (see Fig. 6). The receiver and transmitter of such a direct-conversion transceiver could have many stages in common and no critical IF at all, while the TX delay would no longer be limited by xtal oscillators.

Moving to higher speeds we radio amateurs will also have the opportunity to explore different antenna position, polarization or other diversity techniques to improve the reliability of contacts affected by multi-path or other propagation anomalies. High-speed data transmission in these conditions and at these data rates is relatively new also to professionals, so we can really contribute something new to the propagation science.

6. Acknowledgements

The SuperVozelj project is not just my own work. It also represents the work of a large number of radio amateurs and here I am only going to acknowledge the most important contributions:

Knut Brenndoerfer, DF8CA, helped me obtaining state-of-art semiconductors for the 13cm PSK transceiver. Without his help the transceiver would be even more complicated using obsolete parts.

Mijo Kovacevic, S51KQ, and Tomi Kacin, S57BKC, designed some of the printed circuit boards of the SuperVozelj computer and modems.

Iztok Saje, SS2D, made several upgrades to my original software to make it compatible with different BBS, DXCLUSTER and other packet-radio node programs.

Franci Mermal, S51RM, and Sine Mermal, S53RM, developed new, more compact printed circuit boards for the SuperVozelj and for the 70cm WBFM transceiver.

7. Information sources

All of the information about the SuperVozelj is freely available. Most of the hardware has already been published in our national Slovenian amateur-radio magazine "CQ ZRS". The 13cm PSK transceiver will be published soon, probably in the next issues.

The SuperVozelj source code programs and instructions are regularly loaded on LJUBBS:SSOBOX under the directory DSP3MV. However, most of the instructions and comments to the source code are only available in Slovenian language.

List of figures:

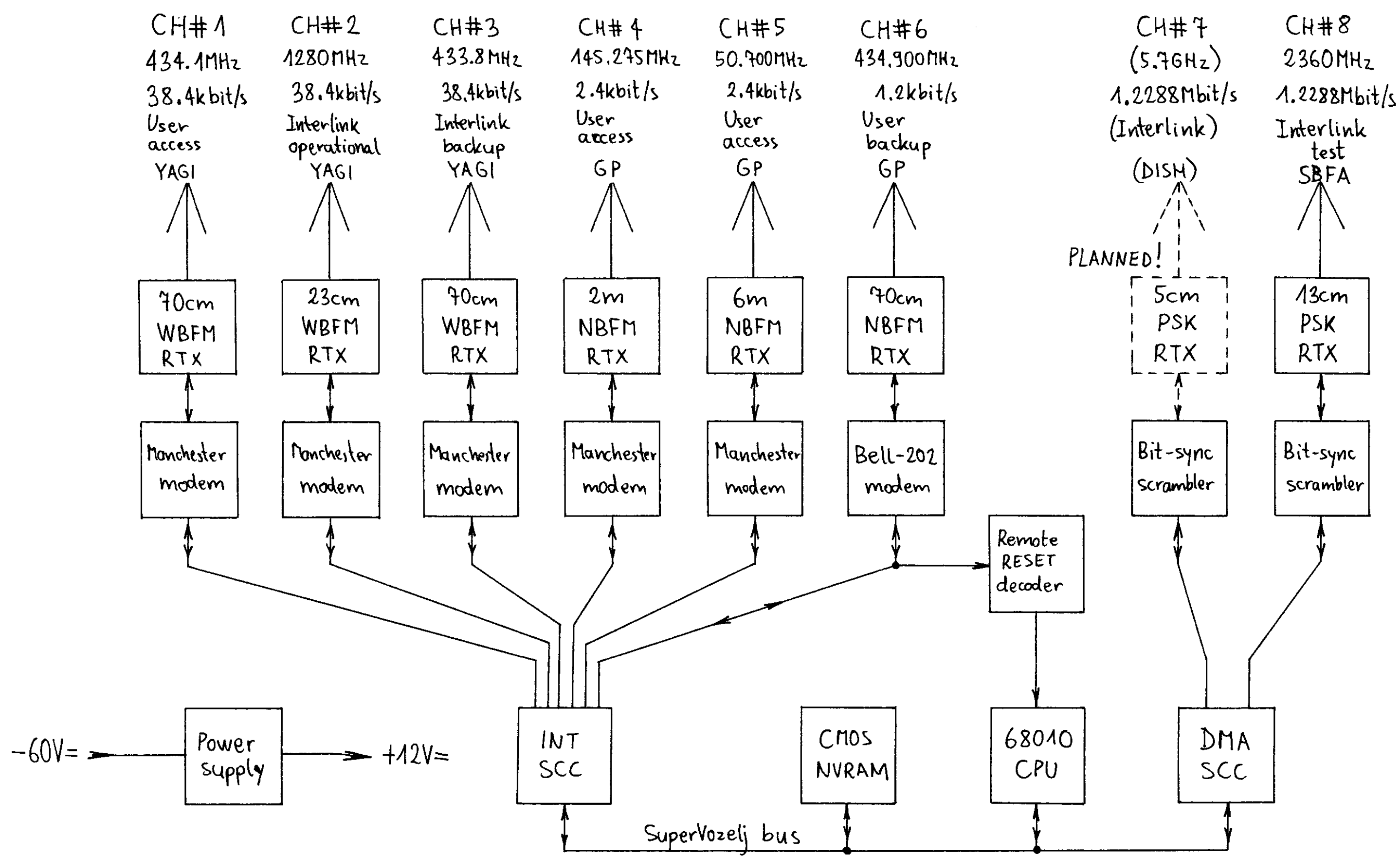

Fig. 1 - Block diagram of the SuperVozelj packet-radio node GORICA:S55YNG.

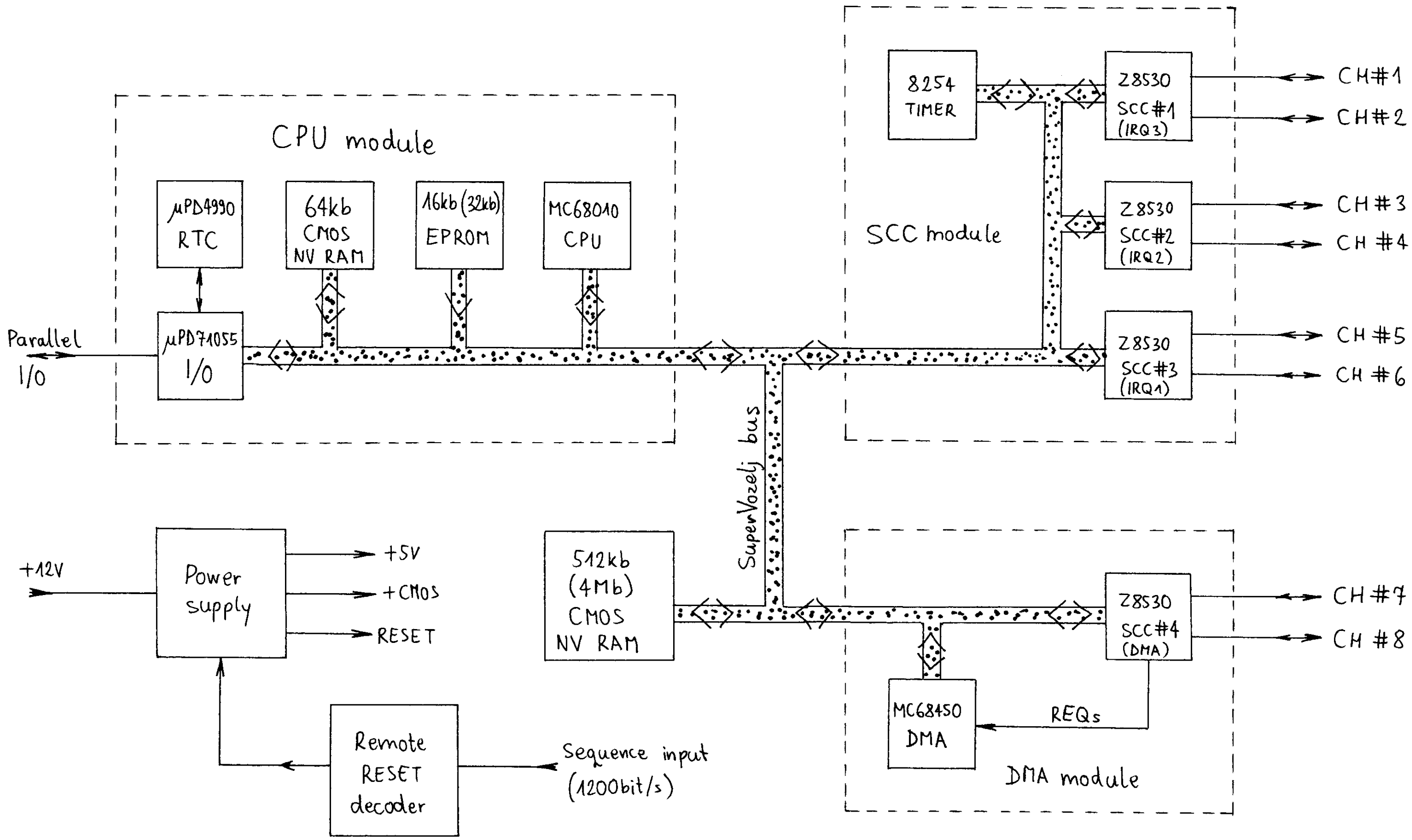

Fig. 2 - Block diagram of the SuperVozelj packet-node computer.

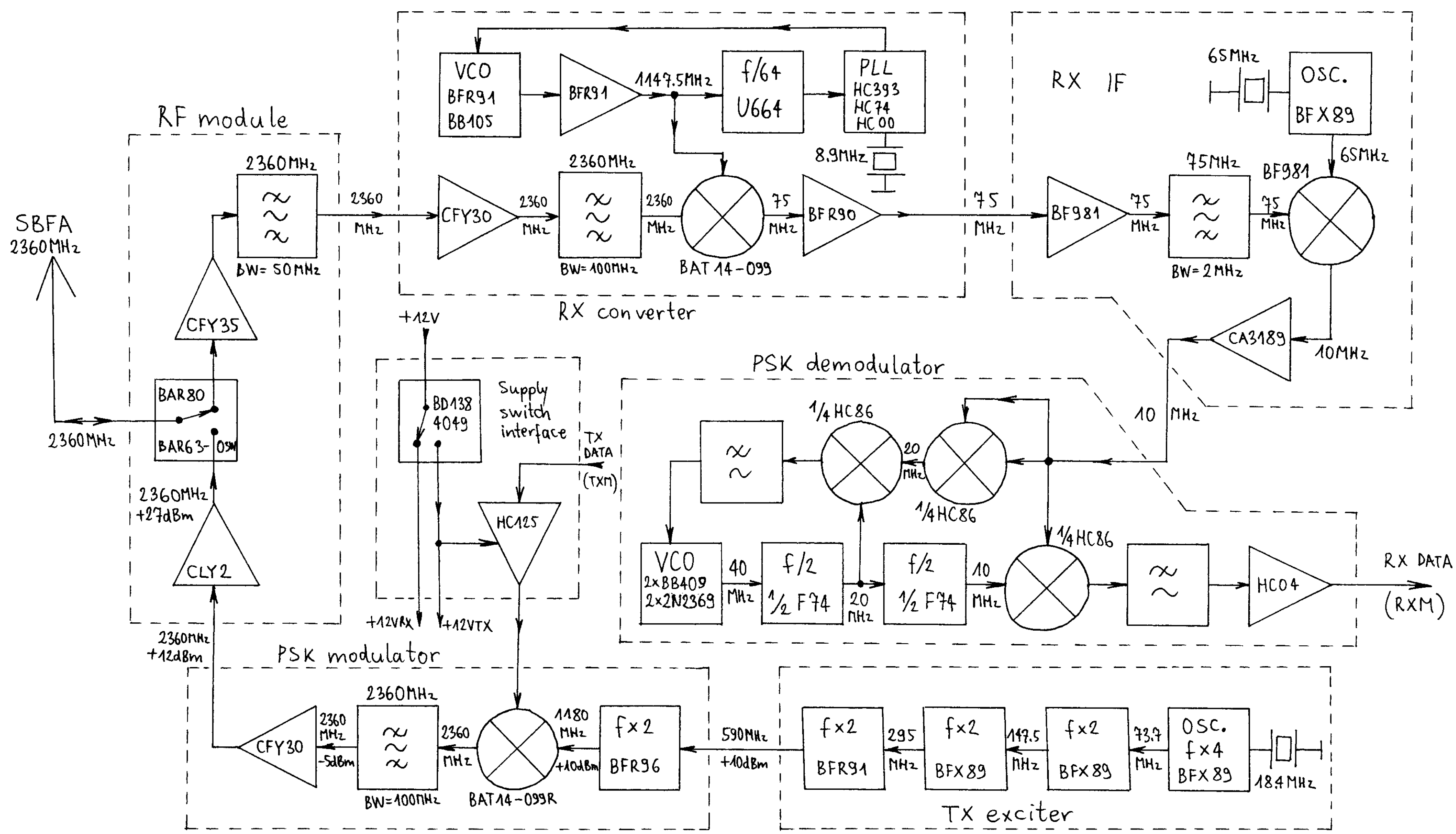

Fig. 3 – 13 cm PSK transceiver block diagram (2360MHz / 1.2288 Mbit/s).

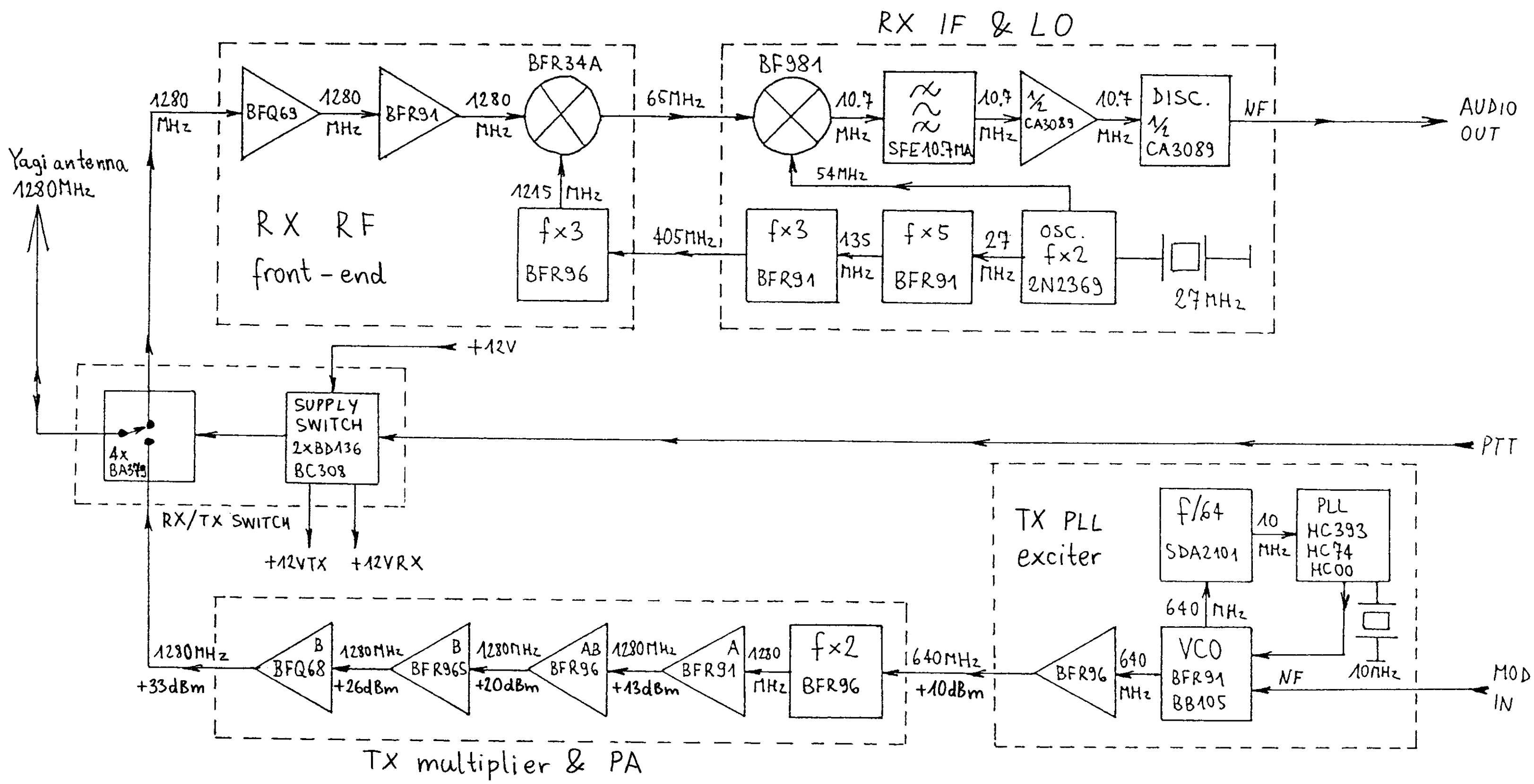

Fig. 4 – 23 cm WBFM transceiver block diagram (1280 MHz / 38.4 kbit/s).

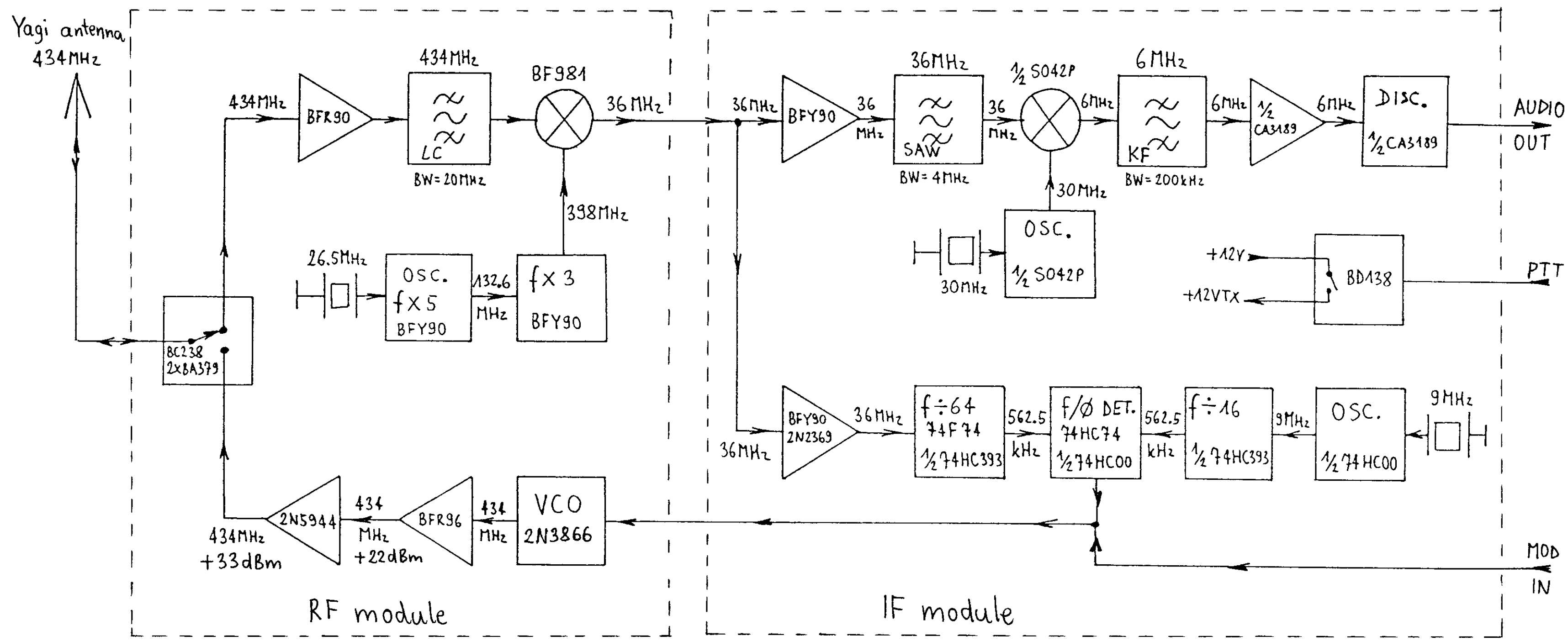

Fig. 5 – 70 cm WBFM transceiver block diagram (434MHz / 38.4kbit/s).

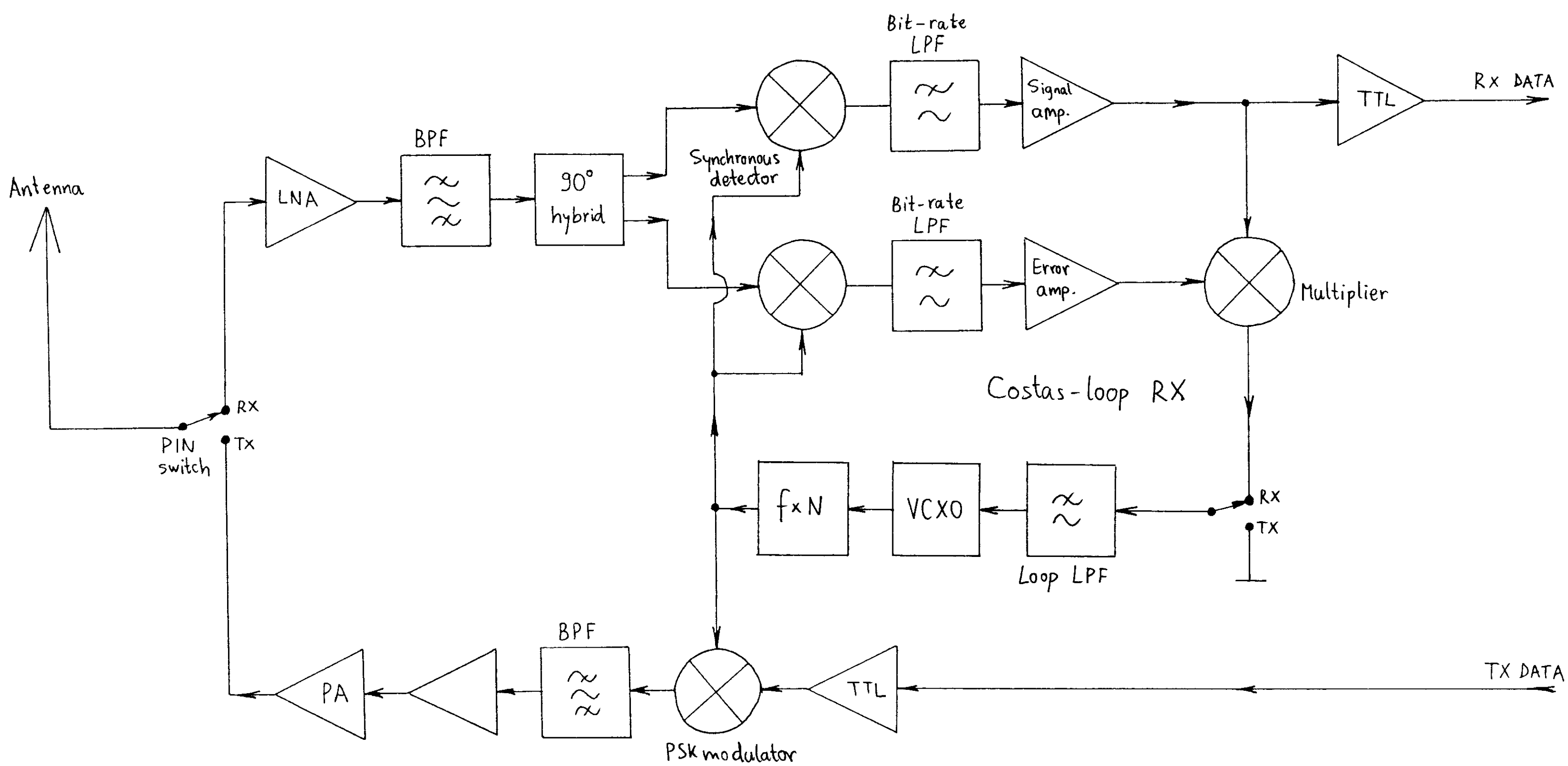

Fig. 6 - Direct-conversion PSK data transceiver.