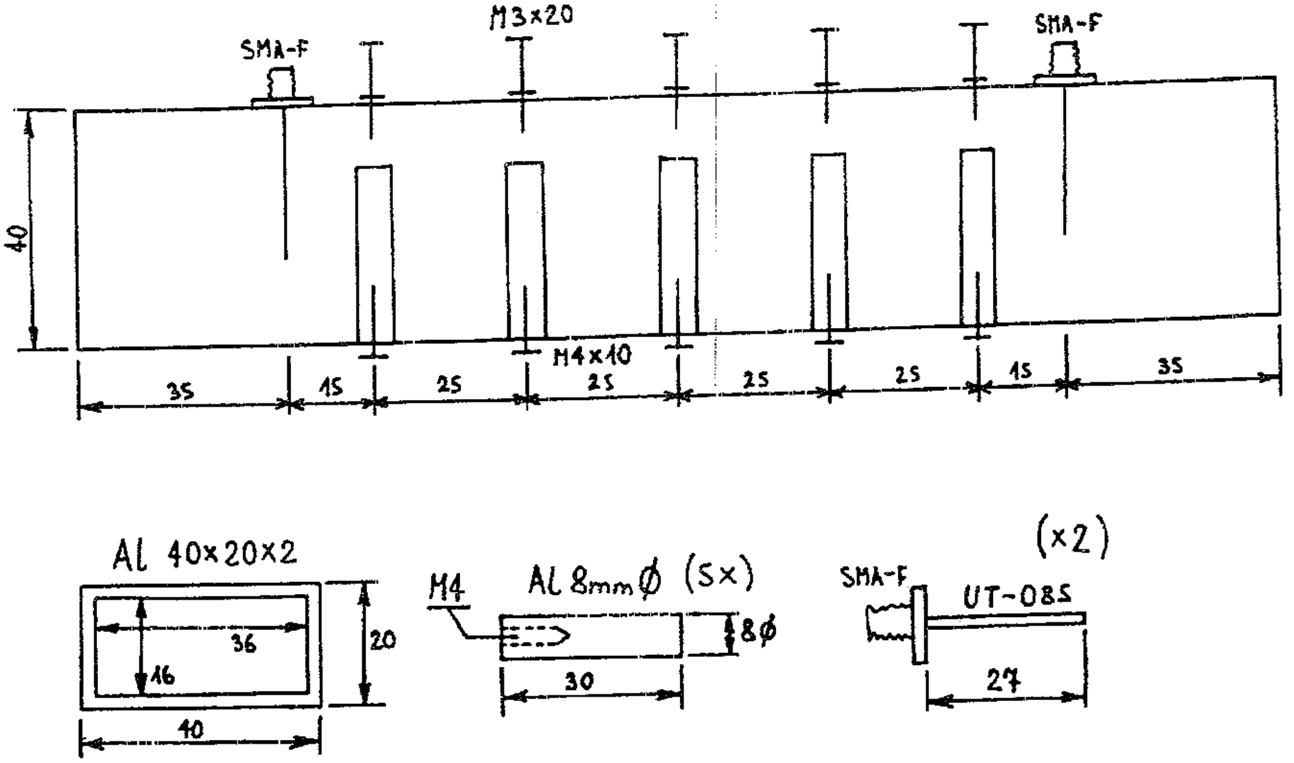

Fig.4: Cavity Bandpass Filter

The described bandpass filter is built inside a piece of standard aluminium tube of rectangular cross section with the external dimensions of 40mm x 20mm and 2mm wall thickness. Such rectangular aluminium tube can be found elsewhere in Europe. Of course, its internal dimensions of 16mm x 36mm are the most important parameter while building a cavity filter.

The construction of the cavity bandpass filter is shown on Fig.4. The filter includes five quarter-wavelength resonators made from 8mm diameter aluminium rod. All five resonators are oriented in the same direction ("comb" filter) to decrease the coupling between adjacent resonators. In this way the overall dimensions of the filter are smaller than in the case of an "interdigital" arrangement of the resonators.

The input and output couplings are made by two small rod antennas, supported by the corresponding SMA connectors. The coupling is adjusted by the length (around 27mm) of the two antennas made of thin copper tube (UT-085 shield). The coupling between resonators is defined by the distance 25mm between resonator centres and sets the filter bandwidth to about 25 MHz.

Five M3 x 20mm tuning screws are used to bring all five resonators to the desired operating frequency. The tuning screws are inserted from the opposite narrow side of the cavity and secured with a lock-nut after tuning.

The cross section of the cavity is small enough that the electromagnetic field exhibits a very fast exponential decay at both ends of the rectangular aluminium tube. Covers are therefore not required for the electrical performance of the filter. On the other hand, covers are useful to keep dust and dirt outside. Covers may extend up to 10mm inside the cavity or stay at least 25mm away

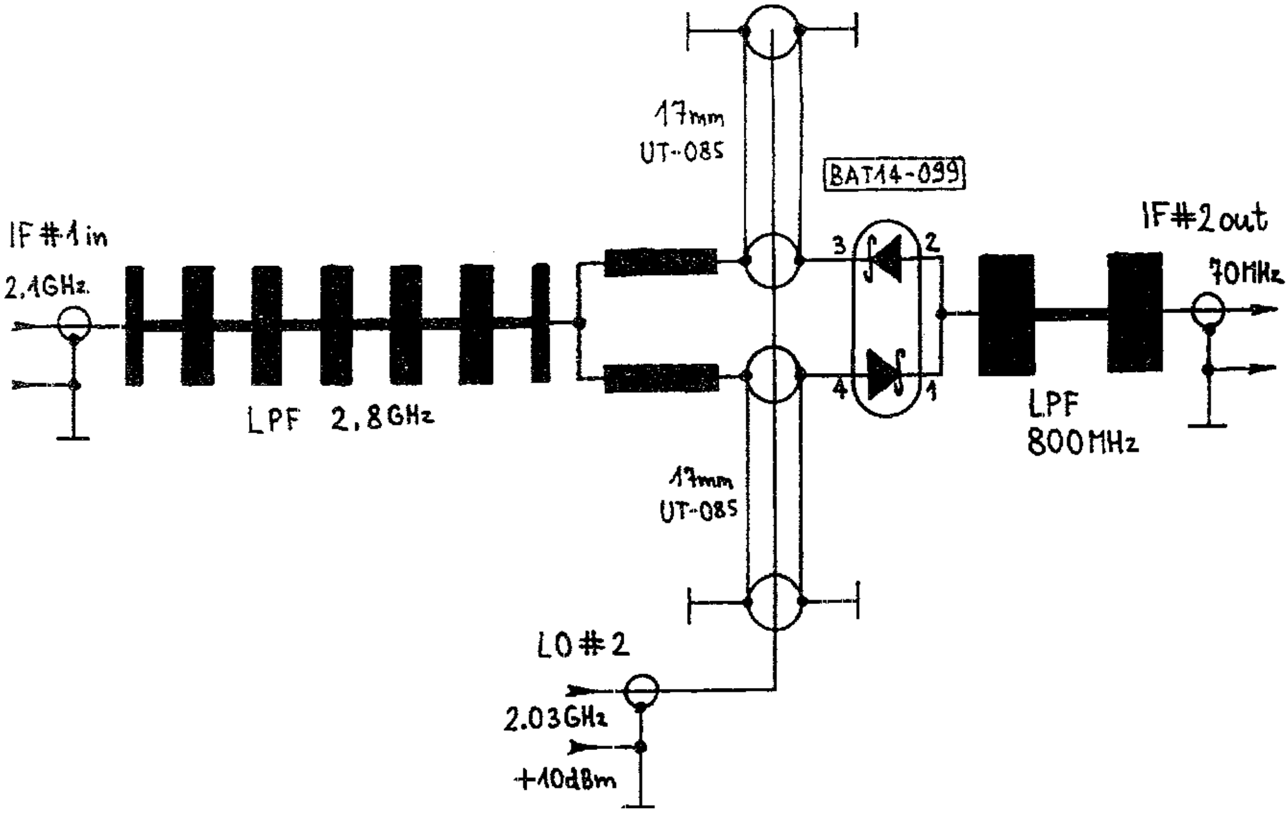

Fig.5: Second Mixer

from the coupling antennas without having any influence on the filter performance.

The described cavity bandpass filter provides over -100dB of suppression for the second-conversion image frequency around 1.94 GHz. The insertion loss is only around -2dB at the nominal first IF frequency of 2.1 GHz and over -100dB outside the passband anywhere between 0 and 4 GHz. Spurious higher-order resonances appear above 4 GHz, when the aluminium tube starts operating as a waveguide. A cavity filter alone is therefore not sufficient Additional microstrip lowpass filters are therefore included in both the first and second mixer modules to suppress the spurious cavity responses above 4GHz.

The cavity design allows narrowing the passband down to just a few MHz. A bandwidth of 25 MHz was selected to allow a narrow sweep of the second LO, to avoid some spurious responses of the first mixer and finally to allow for some frequency drift of the second VCO.

5.
SECOND MIXER

The requirements for the second mixer are not as far as severe as for the first mixer, since most unwanted signals have already been removed by the cavity bandpass filter. Also the signal levels are about -10dB weaker due to the conversion loss of the first mixer and cavity bandpass insertion loss. Calculations and experiments show that no amplifier stages are required between the two mixers if the maximum dynamic range is desired.

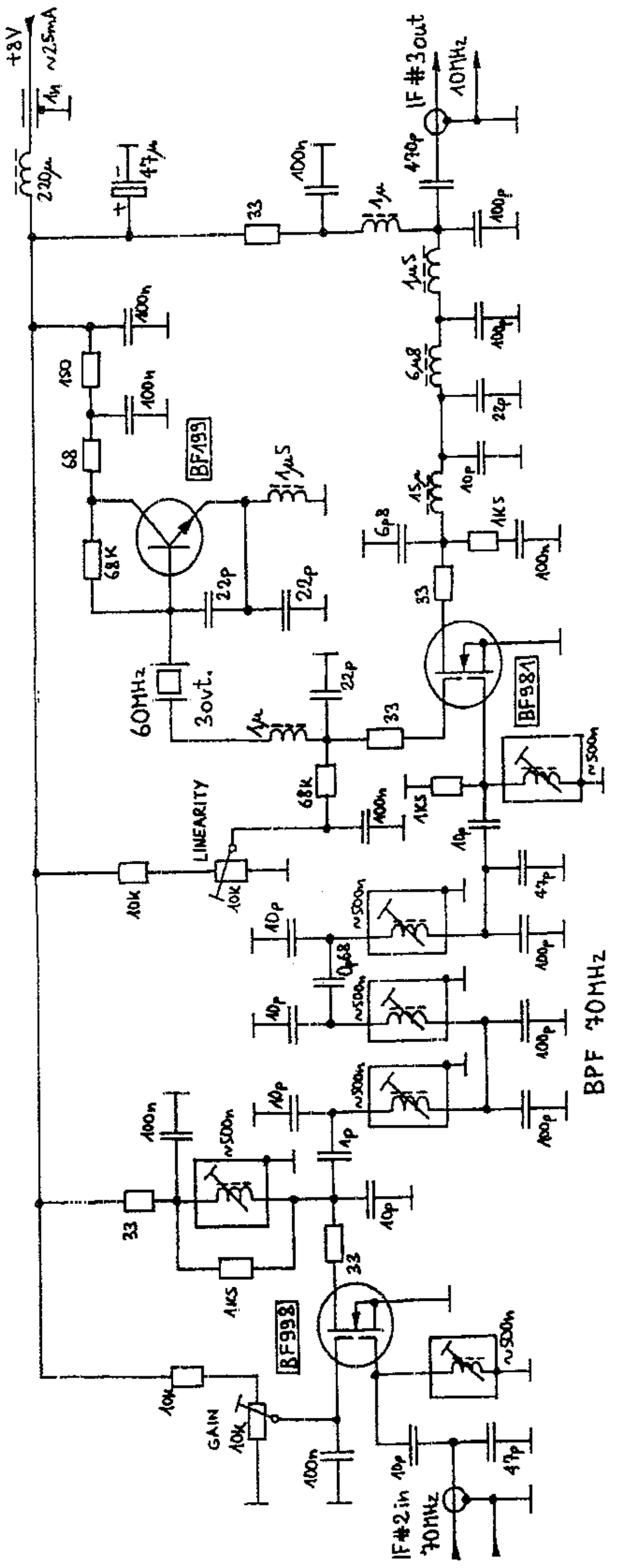

Fig.6: Third Mixer

The design of the second mixer is very similar to the first mixer, except that the input and output are interchanged, as shown in Fig.5. The second mixer is also using a BAT14-099 double Schottky diode and a balun made from UT-085 semi-rigid cable. Since the second mixer operates in a narrow frequency band, damping resistors and other compensation components are not required.

The second mixer module includes low-pass filters both at the input and output. The input lowpass filter cuts above 2.8 GHz to suppress the spurious cavity responses above 4 GHz. The output lowpass cuts above about 800 MHz to suppress unwanted mixing products and feedthrough of the LO signal.

6.

THIRD MIXER

The first IF of the spectrum analyser around 2.1 GHz is far too high for the different IF filters and logarithmic detector. A more suitable choice for the final IF is 10 MHz. The latter can be conveniently reached from 2.1 GHz in two down conversion steps.

Due to the relatively low frequencies and low signal levels, the requirements for the third mixer are not particularly severe. An additional requirement is the maximum bandwidth B = 4 MHz that requires a carefully designed bandpass filter at 70 MHz and wideband impedance matching at the final IF of 10 MHz.

The circuit diagram of the third mixer and related components is shown in Fig. 6. The circuit includes a low-noise amplifier at 70 MHz, followed by a LC bandpass filter for 70 MHz and a dual-gate MOSFET mixer. The 70 MHz low-noise amplifier (BF998) is the only true amplifier stage in the whole receiving chain of the spectrum analyser. The only purpose of this stage is to compensate for the conversion loss in the mixers. Any gain increase or additional amplifier stages would just impair the dynamic range of the spectrum analyser.

The LC bandpass filter at 70 MHz has two functions. First, the image response of the third mixer at 50 MHz has to be suppressed. Second, the widest IF bandwidth of the spectrum analyser is defined mainly by the 70 MHz bandpass filter. The bandwidth of the 70 MHz LC bandpass filter itself is around 5 MHz, limiting the overall bandwidth of the complete receiving chain to about 4 MHz. The 70 MHz LC filter is built with adjustable coils (about 500nH) wound on shielded supports for IF transformers. The input and output are terminated with 1.5k resistors.

The third mixer is built with a dual-gate MOSFET BF981. The input 70 MHz signal is fed to the first gate while the 60 MHz LO is applied to the second gate. The mixer is followed by a lowpass impedance-matching network. The latter should both remove the 60 MHz LO signal and other unwanted mixing products as well as provide a wideband transformation of the MOSFET high output impedance down to 50Ω.

The design of a suitable lowpass/matching network is complicated, since the required bandwidth is comparable to the centre frequency 10 MHz. Impedance matching is therefore performed in several steps with lowpass LC networks.

The circuit shown in Fig.6 allows reasonable impedance matching in the frequency band 6...15 MHz and a high suppression of the 60 MHz LO at the same time. The circuit is built with fixed inductors of the size and shape of 1/4W or 1/2W resistors. The third LO includes an overtone crystal for 60 MHz and a BF199 transistor. The 1.5uH inductor in the emitter of the BF199 forces the crystal to oscillate on the third overtone. The crystal is also used at the same time as a filter for the output signal fed to the mixer.

The 1uH inductor in series with the crystal further reduces the amount of harmonics fed to the mixer. Finally, unwanted mixing products can be further suppressed by carefully setting the MOSFET bias with the trimmer "LINEARITY".

The trimmer "GAIN" is set for the lowest practical gain of the BF998 that does not impair the noise figure of the whole spectrum analyser.

7.
LC FILTERS

The output of the third mixer can be fed directly to the input of the logarithmic detector, setting the IF bandwidth to about 4 MHz. If a narrower IF bandwidth is desired, additional bandpass filters are required between the third mixer and the logarithmic detector. LC filters can be used for bandwidths above 100 kHz, while crystal filters are required for even narrower bandwidths.

A spectrum analyser should include several different IF filters, to be included as required in the IF chain. Filter switching can hardly be performed by standard mechanical switches only, since a crosstalk better than -100dB is required between the input and output of a filter. A better solution is electronic filter switching with PIN diodes. Each filter should also include an amplifier to compensate for the insertion loss of the filter. In this way the measured signal strength will remain the same while switching among different IF filters.

Professional spectrum analysers usually allow the selection of the IF bandwidth in steps of 1/3/10 etc. On the other hand, practical requirements show that just a few different bandwidths are required above 100 kHz. Many different bandwidths are only required below 100 kHz, where the IF bandwidth also defines the sweep time and limits the display update frequency.

The described spectrum analyser includes two different LC filters with the bandwidths set to 700 kHz and 150 kHz. In addition, the crystal filter bandwidth can be adjusted in smaller steps to 50 kHz, 20 kHz or 10 kHz. Finally, with no additional filters an IF bandwidth of 4 MHz is obtained, providing a total selection of six possible IF bandwidths.

The two additional LC filters are shown in Fig.7. Each filter includes a switching network with four diodes BA423. The filter is inserted in the IF chain by simply applying the corresponding +8V supply. At the same time the BF199 transistor cuts the direct signal path and further improves the crosstalk attenuation between the input and output of the filter.

The 700 kHz wide LC filter includes four adjustable coils (about 10uH), wound on shielded supports for IF transformers. The BFR96 amplifier compensates the insertion loss of this filter. Of course the exact amount of gain depends on the loss in the coils and can be adjusted with the 220Ω trimmer.

The 150 kHz wide LC filter includes two separate filters, each including two tuned circuits. The required inductors are in the range of 2.2uH. All four coils are wound on slightly larger shielded supports for IF transformers to achieve an unloaded Q of about 100. The insertion loss of both narrow LC filters is compensated by the BF981 amplifier. The gain of the latter is adjusted by the bias voltage (10kohm trimmer) on the second gate.

The LC filter module requires three different supply voltages. The +8V supply should be present at all times to bypass the filters while the latter are turned off. The +8V/700 kHz supply inserts the 700 kHz wide filter while the +8V/150 kHz supply inserts the 150 kHz wide filter. Both the input and output of the module should remain matched to an impedance of 50Ω at all times.

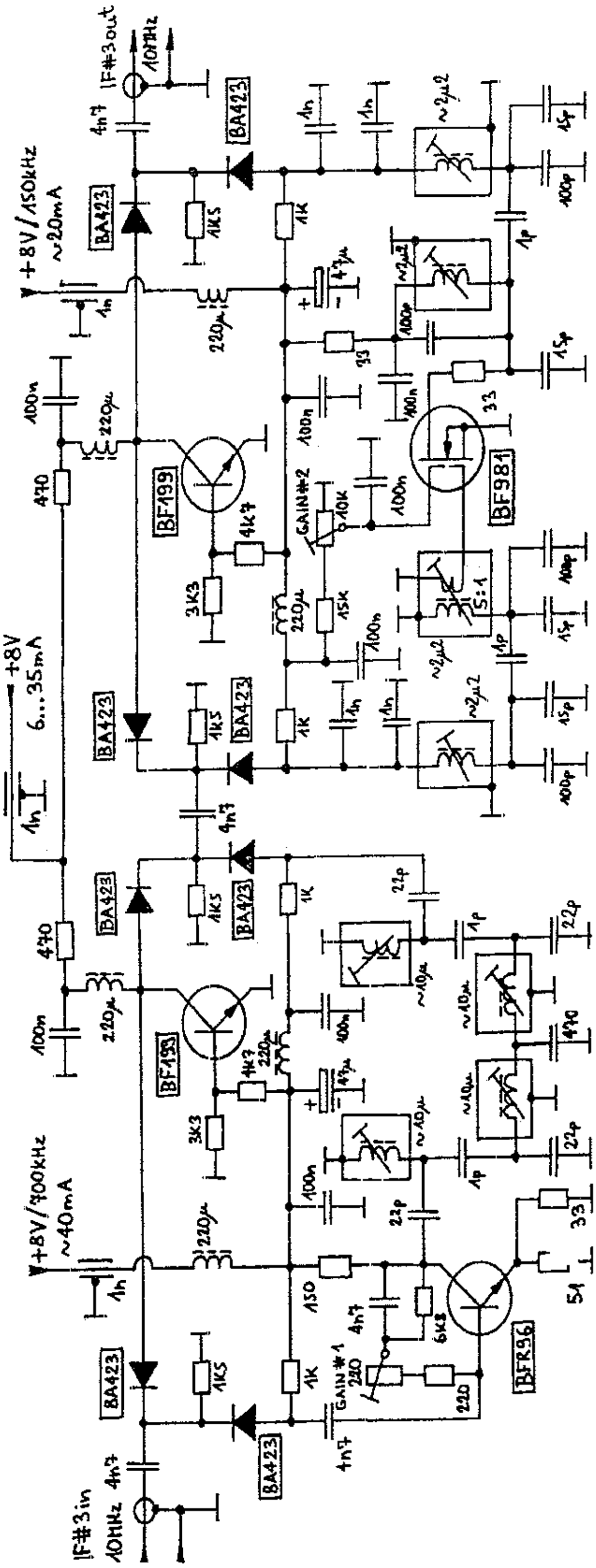

Fig.7: LC Filters

8.
CRYSTAL FILTER

Spectrum analysers require somewhat different IF filters than those installed in communication receivers. Communication receivers usually require filters with a flat passband, to avoid modulation distortion, and a very steep increase of the insertion loss immediately outside the useful passband, to reject adjacent channels. Such filters are not suitable for spectrum analysers, since their time response is rather slow (ringing!) compared to the filter bandwidth.

A slow filter response and/or ringing is especially harmful at small bandwidths, where the time response of the filter defines the sweep time and display update period. Commercial crystal and ceramic filters are therefore almost useless in spectrum analysers. A suitable crystal filter or set of different filters has to be specially built for a spectrum analyser.

A spectrum-analyser IF filter should have a "triangular" frequency response with a sharp peak and smoothly and symmetrically increasing attenuation outside the passband. In practice this requires under critically-coupled resonators or better a series connection of several single-resonator filters and buffer amplifiers, to avoid any interaction among the resonators.

The crystal filter shown in Fig.8 includes a series connection of four independent, single resonator filters. BF199 emitter followers are used to avoid unwanted coupling among the crystals. Each individual filter includes a

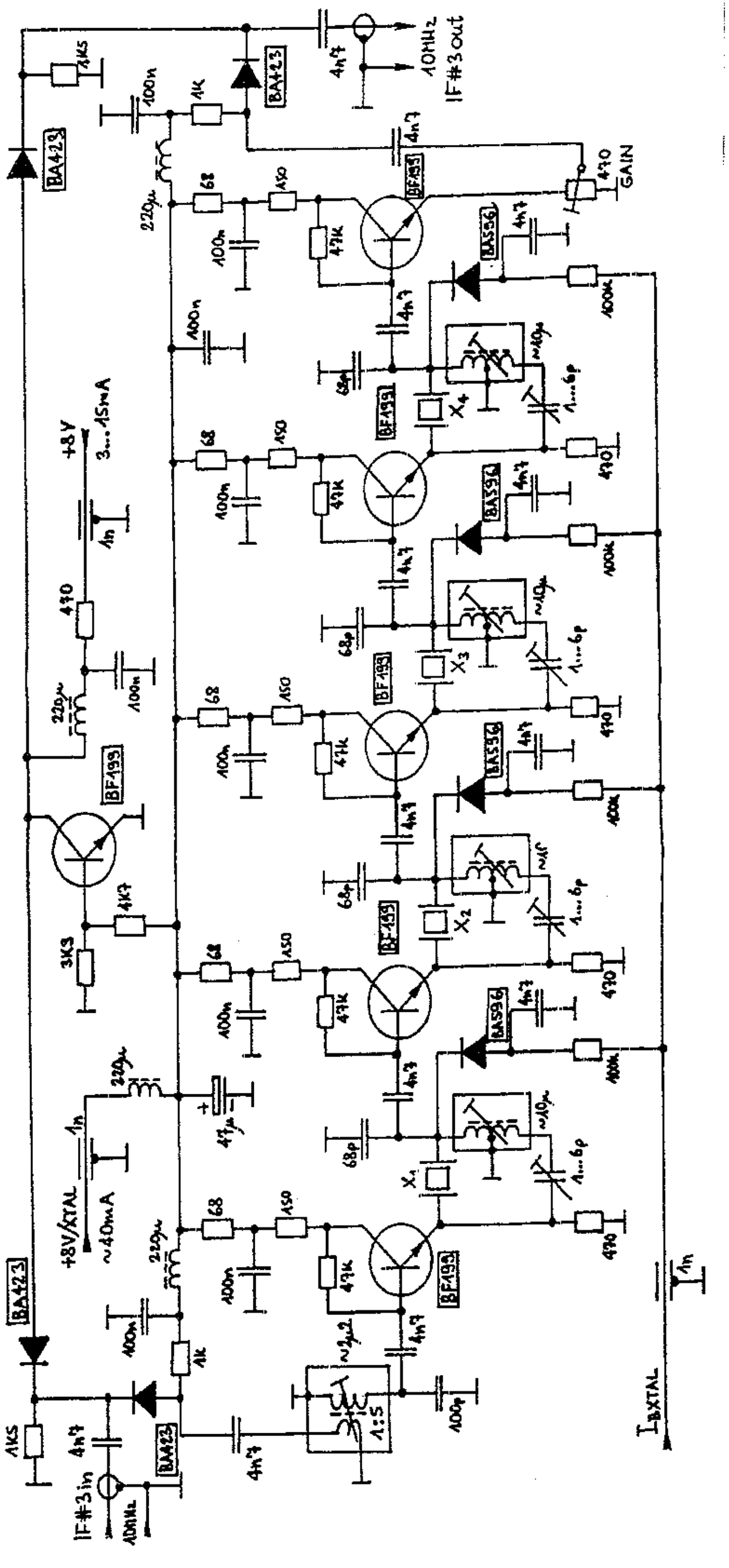

Fig.8: Crystal Filter

single crystal in a balanced network. The capacitive trimmer is used to compensate the capacitance of the crystal. The 10uH centre-tap coil resonates with the 68pF capacitor and compensates the remaining parasitic capacitors of the circuit.

The bandwidth of a single-crystal filter depends mainly on the source and load impedances. The source impedance is kept low by the previous emitter follower. The load impedance is adjustable, since a PIN diode BA596 is connected in parallel to the input of the following emitter follower. The filter bandwidth is therefore adjustable with the DC current IBXTAL fed to the four BA596 PIN diodes.

The crystal filter module includes a switch with four diodes BA423 to insert the filter in the IF chain. The supply voltage +8V should be present at all times to bypass the crystal filter while the latter is turned off. The supply voltage +8V/XTAL inserts the crystal filter. The insertion loss of the latter is mainly compensated by the emitter followers.

Some additional gain is provided by the 1:5 step-up transformer at the input, followed by the first emitter follower. The overall gain is adjusted by the 470Ω trimmer on the output.