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TWO-CHANNEL WEATHER PICTURE RECEIVER WITH OPTIMUM DEMODULATOR Z--ETC(U)
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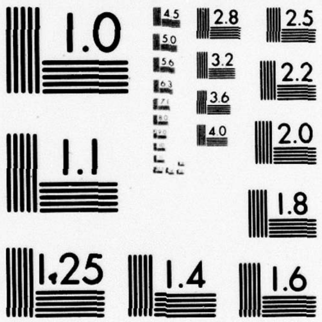

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TWO-CHANNEL WEATHER PICTURE RECEIVER WITH OPTIMUM DEMODULATOR ZEA 1

by

H. J. Fischer, V. Kempe, et al.

EDITED TRANSLATION

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TWO-CHANNEL WEATHER PICTURE RECEIVER WITH OPTIMUM DEMODULATOR ZEA 1

H. J. Fischer, V. Kempe, J. Rienaecker, and K.-H. Schmelovsky

A modern two-channel receiver is described which, employing the knowledge of signal theory, permits the reception of satellite signals with simple, unguided antenna systems. The theoretical bases and an example of a single-channel receiver have already been presented in [1] and [2]. At the Leipzig Spring Fair 1971 the entire weather picture receiving system WES-2 was displayed which consists of the ZEA 1 and the BAG 1. A special publication about the telerecorder will appear in the next issue.

The reception of satellite signals, in contrast to the reception of radio signals from earth-bound stations, displays a number of peculiarities:

time limitation of the possible reception due to the orbital parameters of the satellites,

Doppler shift of the carrier frequency of the satellite transmitter as a result of its own movement,

sudden changes of the polarization and amplitude of the signal,

generally small field strengths at the receiving location due to the output limitation on board the satellite and the great distance between the transmitter and receiver.

From what has been said it is obvious that a receiver for such signals to the greatest extent possible should possess high sensitivity, synchronous demodulation, and polarization automatic timing control. The special demodulator also provides the possibility of Doppler frequency compensation.

As a result of the employed two-channel principle and the attainment of an optimum output signal from two input signals coming from two antennas arranged orthogonally to each other, with small field strengths in comparison to conventional receivers a considerably more favorable signal-to-noise ratio of the demodulated signal is obtained. With this receiver one can certainly receive signals from a satellite which is at least 15° over the horizon using a simple, unguided antenna.

The Signal Path to the Demodulator.

The fundamental operating principle of the receiver is shown in the block circuit diagram (Fig. 1).

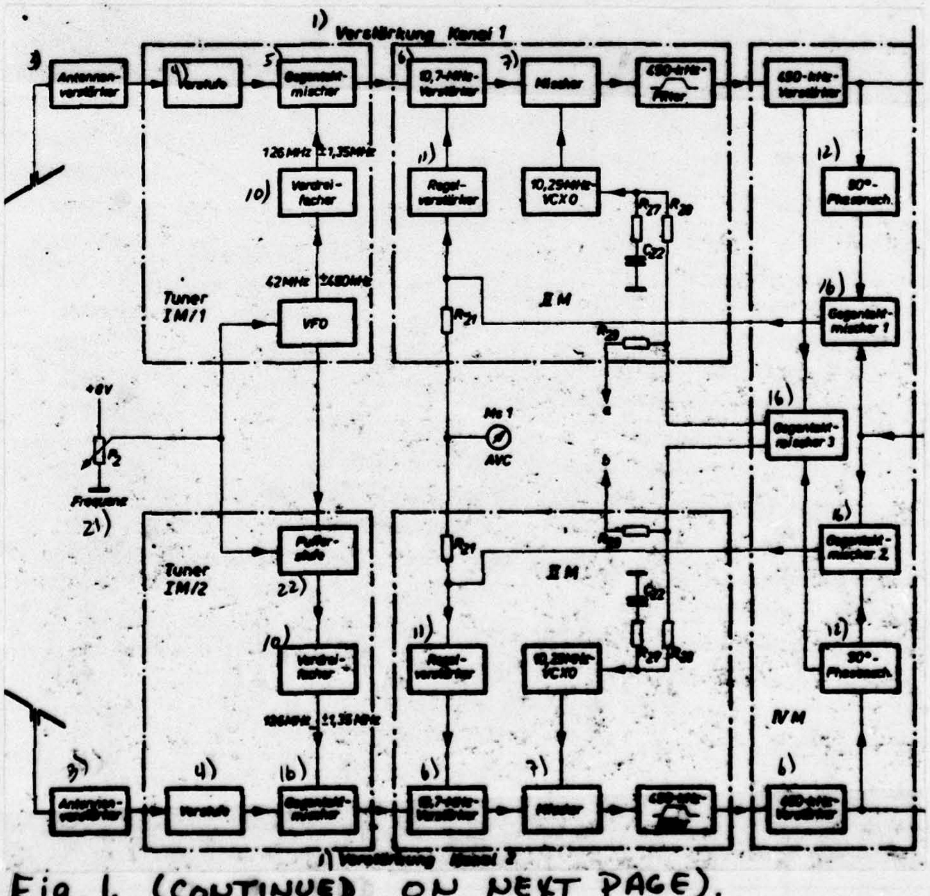


Fig. 1. (CONTINUED ON NEXT PAGE).

Fig. 1. Block circuit diagram of the ZEA 1 receiver. KEY: 1) amplification channel; 2) combination of channel 1 and 2 and demodulation; 3) antenna amplifier; 4) preliminary stage; 5) push-pull mixer; 6) amplifier; 7) mixer; 8) electronic potentiometer; 9) analog control; 10) tripler; 11) control amplifier; 12) phase shifter; 13) phase detector; 14) oscillator; 15) channel; 16) push-pull mixer; 17) control loudspeaker; 18) buffer stage; 19) AF-amplifier; 20) volume; 21) frequency; 22) buffer stage; 23) adding stage; 24) low-pass filter and amplifier; 25) AF-output stage; 26) output; 27) amplitude modulator; 28) band-pass filter.

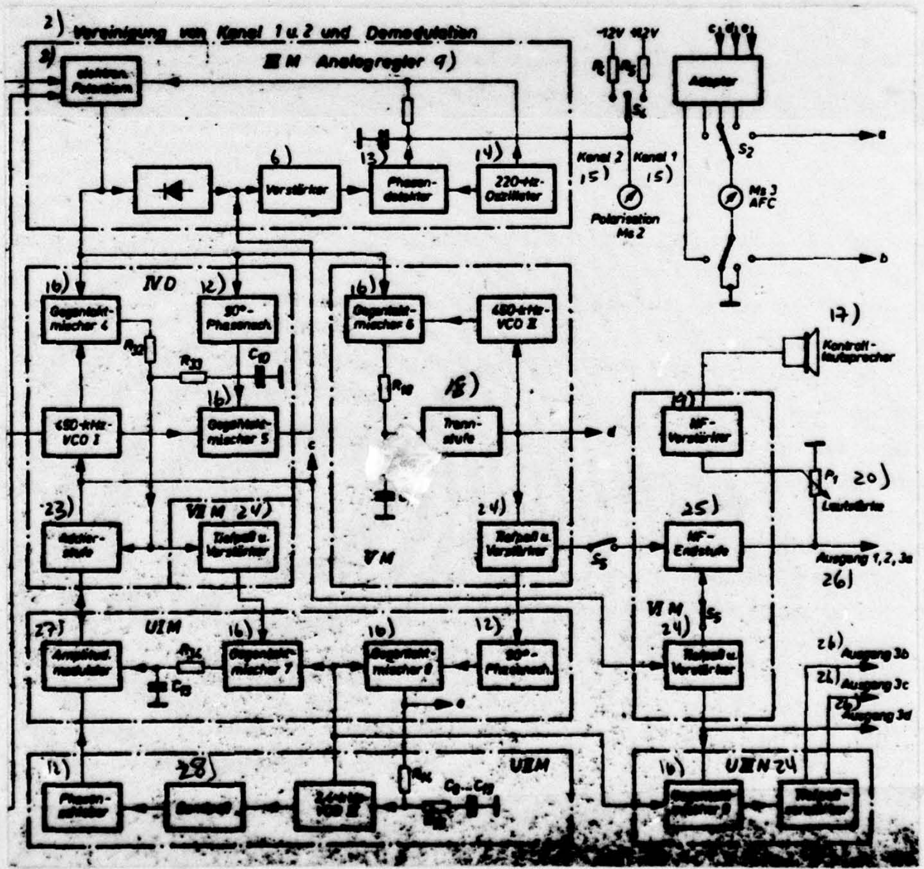


Fig. 1. (CONTINUED).

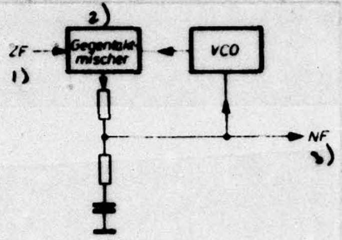
The received signals, coming from two antennas with orthogonal polarization planes, are amplified by two separate, low-noise, antenna amplifiers and fed to the receiver. From the receiver input to the output of the 450-kHz-IF-amplifiers the signals are amplified in two separate channels. The frequency, variable with a tuning potentiometer by +-450 kHz, of a variable frequency oscillator (VFO) of 42 MHz common for both channels, is tripled and mixed with the signal frequency in both tuners. The signals converted to the intermediate frequency of 10.7 MHz are amplified and with an additional mixing stage are each converted to 450 kHz. The oscillator frequencies of 10.25 MHz which are necessary for this are supplied by two voltage-controlled quartz oscillators (VCXO). After passing through a magnetomechanical filter and a 450-kHz-IF-amplifier the IF-signals of both channels arrive at the analog regulator. There they are combined into one signal which is fed to the FM-demodulator.

The Phase-Lock Circuit as FM-Demodulator.

The FM-demodulator (board IV D) which will be discussed below is a phase-lock demodulator essentially consists of a push-pull mixer (push-pull mixer 4), a voltage-controlled 450-kHz oscillator (VCO I) and an RC-low-pass filter for the output signal of the push-pull mixer which controls the VCO (Fig. 2).

Fig. 2. Principle of FM-demodulation through a phase-lock circuit.

KEY: 1) IF; 2) push-pull mixer; 3) AF.



In the steady-state condition the VCO-signal is phase-shifted to the IF-signal by almost 90°. The phase error $\Delta\phi$ compared to 90° between the reference and the signal provides an output voltage on the push-pull mixer of $U = k \sin \Delta\phi$, which adjusts the VCO to the frequency of the IF-signal. The d-c voltage component of this control voltage is indicated by Ms3 for facilitation of receiver tuning.

If the IF-signal is frequency-modulated then the automatic timing control voltage of the VCO is proportional to the frequency deviation, i.e. it supplies the demodulated AF. The time constant of the RC-integrator determines the limit of the modulation frequency up to which the VCO is controlled and therewith the bandwidth of the phase-lock circuit.

Control of Both Channels at the Same Level of the Wanted Signal Output

If one supplies the 90°-phase-shifted IF-signal, shifted with a phase shifter, and the signal from the VCO I to an additional push-pull mixer then one obtains on this push-pull mixer a direct current proportional to the carrier which can be used, for example, for amplification control. With one push-pull mixer each (push-pull mixers 1 and 2 on board IV M) for each channel a control voltage for amplification control of the particular channel is thus obtained proportional to the signal amplitude. This voltage is amplified in each case by a control voltage amplifier and controls a stage of the 10.7-MHz-IF-amplifier (on board II M). The control range is about 50 dB and the control slope is so steep that in the the control range the signal amplitude is held practically constant. The sum of the control voltages of both channels is indicated by Ms 1.

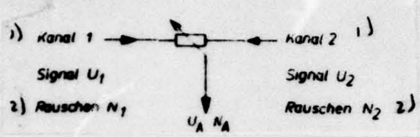
Phase Synchronization of Both Channels

So that the output signals of both channels are also in the same phase the signals from channel 1 and 2 are compared with each other with a phase detector (push-pull mixer 3 on board IV M) and the signal from channel 2 runs additionally through a 90°-phase shifter. Therewith the phase detector supplies a voltage proportional to the phase error between the signals of both channels and this voltage, working in opposite direction, controls both voltage-controlled quartz oscillators (on board II M). If the frequency of both VCXO coincides with a control voltage "zero," then the 450-kHz output signals of both channels are of the same phase. Different transit times in the two channels consequently have no effect on the likeness of phase of the 450-kHz output signals. For checking phase likeness the control voltage for the VCXO can be monitored with the Ms 3.

The Combination of the Output Signals of Both Channels into One Total Signal with Optimum Signal-to-Noise Ratio.

Inasmuch as there is a signal at both receiver inputs, at the input of the analog control (board III M) there are two like-phase signals with the same amplitude $U_1 = U_2$ but with any noise level dependent on the receiver input signal (Fig. 3).

Fig. 3. Formation of the total signal U_A from the output signals of channels 1 and 2. KEY: 1) channel; 2) noise.



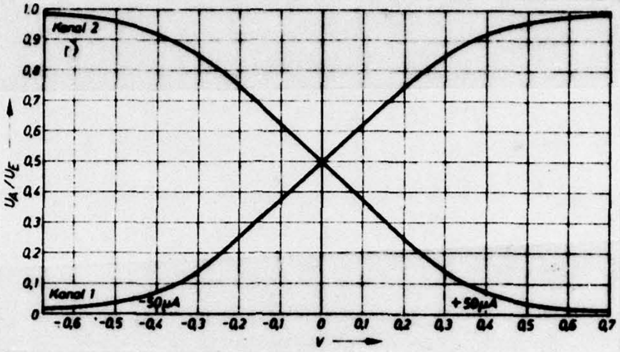
These signals are each fed to one end of a potentiometer - in the analog regulator, an electronic potentiometer. Since the signals U_1 and U_2 are of the same phase for the amplitude of the output signal U_A :

$$U_A = \frac{1}{2} U_1 (1 - \alpha) + \frac{1}{2} U_2 (1 + \alpha),$$
$$-1 \leq \alpha \leq +1,$$

whereby the factor α in the case of the electronic potentiometer is proportional to the control voltage only in a rough approximation (Fig. 4).

Fig. 4. Characteristic of the electronic potentiometer of the analog control ($U_E = U_1$ for channel 1, respectively, $= U_2$ for channel 2).

KEY: 1) channel.



With $U_1 = U_2$ the output signal is independent of the setting of the "slider." Since the noise powers N_1 and N_2 are not correlated for the noise power N_A at the output:

$$N_A = \frac{1}{4} N_1 (1 - \alpha)^2 + \frac{1}{4} N_2 (1 + \alpha)^2$$

i.e., there is a potentiometer setting for which the output noise power N_A has a minimum.

The total output (noise power plus signal power) can be measured if one does not rectify the total signal coherently. With effective value rectification at the output of the rectifying diode there would result a voltage

$$U_{gl} = \sqrt{U_A^2 + \frac{N_A}{R}}.$$

Since U_A is held constant the minimum of the diode voltage must be sought.

A small alternating voltage which is supplied by a 220-Hz oscillator is added to the control voltage of the electronic potentiometer, i.e., the working point of the potentiometer and therewith also the output noise level N_A vary slightly in the 220-Hz rhythm. As long as the optimum working point, i.e., the noise minimum is not reached, one half-wave of the control voltage will lead to a greater output noise level than the other. If one supplies the output voltage of the electronic potentiometer to a rectifying diode then one obtains a directional voltage which with a constant useful signal is dependent only on the noise level, i.e., it contains a 220-Hz AF-component which through phase and amplitude contains the information on the deviation of the optimum from the present working point. This AF-component is amplified and compared with the oscillator voltage in a phase detector. The output voltage of the phase detector adjusts the electronic potentiometer in the direction of the optimum working point. This voltage is indicated with Ms 2. With switch S4 a positive or negative constant voltage can be switched to the electronic potentiometer as a control voltage whereby channel 1 or channel 2 is switched through to the output.

If the prerequisite is not satisfied that both signal levels U_1 and U_2 are equal at the input of the analog control, e.g. if a channel does not supply a signal, then the signal amplitude is also changed with the setting of the "slider." The directional voltage of the diode changes also through a change of the signal amplitude. Thus under these conditions the directional voltage is not a criterion for the optimum signal-to-noise ratio. If one supplies the 90°-phase shifted output signal from the potentiometer and the reference signal from VCO I to a push-pull mixer (push-pull mixer 5 on board IV D), one obtains a voltage proportional to the signal. The difference of the directional voltage of the diode and the output voltage of the push-pull mixer which is proportional to the signal no longer changes in the first approximation if the signal voltage at the output of the potentiometer changes. This difference voltage, or its 220-Hz-AF-component, is therefore used instead of the directional voltage of the diode as a criterion for the optimum working point.

The output signal of the electronic potentiometer is therewith made up of the signals from channel 1 and channel 2 so that the signal-to-noise ratio is nearly optimum. This output signal is now supplied to the demodulator. Finally let it be noted that since the control voltage is derived from the noise power the loop gain of the control circuit is dependent on the noise power, i.e., on the signal-to-noise ratio. Thus the deviation from the optimum, which is necessary for maintaining the control voltage, depends not only on the control voltage but also on the signal-to-noise ratio and indeed in such a way that with a weak and thereby very noisy received signal a smaller residual deviation from the optimum (best signal-to-noise ratio of the output signal of the electronic potentiometer) is achieved than with a strong, low-noise, received signal.

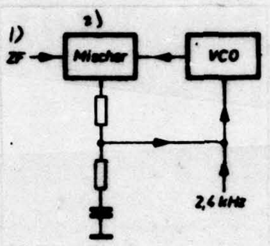
The Demodulator and the Limit of Receiver Sensitivity

The limit of receiver sensitivity is essentially determined by the threshold of the demodulator. Below the threshold the demodulation collapses, i.e., below the threshold the signal-to-noise ratio of the demodulated signal is no longer proportional to the signal-to-noise ratio of the HF-signal, but rather becomes considerably worse (information loss during demodulation). During coherent demodulation through a phase-lock circuit this threshold lies in a more favorable position than in a ratio detector of a conventional FM-receiver. In the phase-lock demodulator this threshold is determined by the bandwidth of the phase-lock circuit. This bandwith, however, is determined by the maximum modulation frequency and by the maximum phase deviation. In the APT-weather satellites the brightness signal is amplitude-modulated to a 2.4-kHz subcarrier and with this subcarrier the satellite signal is frequency modulated. The maximum modulation frequency corresponds to the upper side band of the amplitude-modulated subcarrier of approximately 3.6 kHz. The bandwidth necessary for this signal of the phase-lock circuit of the second order is approximately 10 kHz. If one could considerably reduce the phase deviation on the push-pull mixer then one could reduce the bandwidth of the phase-lock circuit and therewith improve the demodulation threshold. Because of its special structure that is possible for the weather satellite signal.

Improvement of the Demodulation Threshold through the Subcarrier Supporting Circuit

In order to clarify the function of the subcarrier supporting circuit let us look once again at the phase-lock circuit which has already been explained. With a frequency deviation of 10 kHz ("white level") on the push-pull mixer there results a dynamic phase error so that the push-pull mixer supplies the AF-voltage which is necessary for controlling the VCO. This dynamic phase error is $\Delta\phi$. With a frequency deviation of zero ("black level") the dynamic phase error is likewise zero and finally, with an average frequency deviation of 5 kHz, 1/2 $\Delta\phi$. If to the control voltage of the VCO one now adds a 2.4-kHz voltage in proper phase (Fig. 5), which corresponds to a frequency deviation of 5 kHz, then with the white level the phase error will be only 1/2 $\Delta\phi$ since the push-pull mixer needs to apply only half of the AF-control voltage for the VCO (Fig. 5).

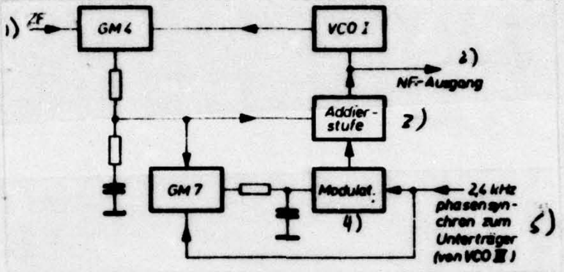
Fig. 5. Input of the 2.4-kHz voltage into the phase-lock demodulator. KE: 1) IF; 2) mixer.



With the black level, however, with a phase error of -1/2 Δφ the given 2.4-kHz-voltage must be compensated and finally with a frequency deviation of 5 kHz ("gray level") the dynamic phase error is zero since the given 2.4-kHz-voltage controls the VCO by +- 5 kHz, i.e., the maximum dynamic phase error is only half as great.

With a control circuit the given 2.4-kHz-voltage is controlled corresponding to the frequency deviation of the IF-signal. In addition the AF-signal which comes from push-pull mixer 4 is demodulated, i.e., it is supplied along with the 2.4-kHz reference signal, which is phase-coherent to the subcarrier, to the push-pull mixer 7 (on board U I M) (Fig. 6).

Fig. 6. Principle of the FM-demodulator with subcarrier supporting circuit. KEY: 1) IF; 2) AF-output; 3) adding stage; 4) modulator; 5) 2.4-kHz phase-synchronous to tae subcarrier (from VCO III).



This AM subcarrier modulator supplies a voltage proportional to the amplitude of the AF-signal and the polarity of this voltage is determined by the phase of the AF-signal. This voltage passes through an RC-low-pass filter and then controls the amplitude of the 2.4-kHz signal supplied to VCO I. The working point of the modulator is set so that without control voltage the 2.4-kHz voltage supplied to the VCO I corresponds to a frequency deviation of 5 kHz. A negative control voltage reduces this standard voltage, a positive control voltage increases it. The amplification of the control loop is 3 which means that with an IF-frequency deviation of 10 kHz a dynamic phase error of 1/8 Δϕ remains on the push-pull mixer 4. The corresponding AF-voltage yields a d-c voltage following demodulation with push-pull mixer 7. Corresponding to the loop gain of 3 the frequency deviation of the VCO I, controlled by the standard voltage, increases from 5 to 8.75 kHz. The difference from the IF-frequency deviation is attributed to the AF-voltage which is supplied from the push-pull mixer 4 and corresponds to the dynamic phase error of 1/8 $\Delta\phi$.

An IF-frquency deviation of zero gives a dynamic phase error of -1/8 $\Delta\phi$. The corresponding negative voltage behind the subcarrier demodulator reduces the 2.4-kHz standard voltage so that this standard voltage corresponds to a frequency deviation of 1.25 kHz of the VCO I. This standard voltage is compensated by the AF-voltage supplied from the push-pull mixer 4 corresponding to the phase error of -1/8 $\Delta\phi$. With an IF-frequency deviation of 5 kHz the dynamic phase error is 0, since the reference voltage controls the VCO I by +-5 kHz.

With the same bandwidth of the phase-lock circuit the maximum dynamic phase error is 1/8 $\Delta\phi$. Thus it is possible to reduce the bandwidth of the phase-lock circuit to 3.6 kHz. That means an improvement of the demodulation threshold by about 4.5 dB. The control voltage of the VCO I, as in the case of the phase-lock demodulator without supporting circuit, supplies the AF output signal of the demodulator. A peculiarity of this circuit is the fact that the loop is closed only when an IF-signal is present on the push-pull mixer 4. Without the IF-signal at the output of the demodulator one obtains the unregulated 2.4-kHz standard voltage ("gray level"). Even when only noise is present on the demodulator the AF output voltage contains the 2.4-kHz standard voltage.

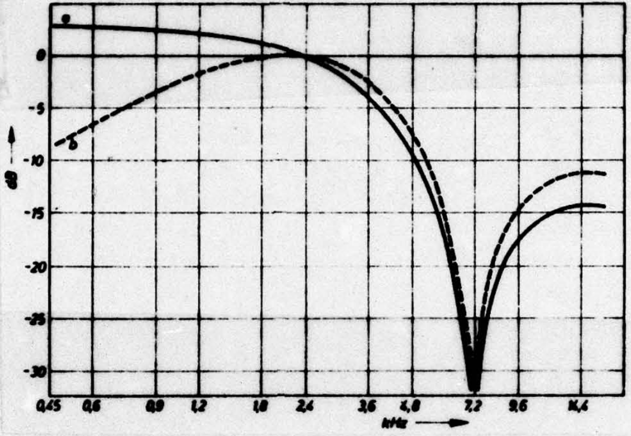
Obtaining a Reference Signal Phase-Coherent tc the Subcarrier.

In the preceding explanation of the subcarrier supporting circuit it was assumed that a 2.4-kHz reference signals is present which is phase-coherent to the subcarrier. This is supplied from VCO III (board UII M) which by push-pull mixer 8 is synchronized to the output voltage of a second independent FM-demodulator. (The FM-demodulator with supporting circuit (boards IV D, UI M, UII M) which has been described thus far shall subsequently be designated as FM-demodulator 1). Since the VCO signal must be in phase to the subcarrier an additional 90° phase shifter is located between the FM-demodulator and the push-pull mixer 8. The second independent FM-demodulator is necessary in order to to avoid cross couplings in the support circuit. This second FM-demodulator is a phase-lock circuit (board V M) with the bandwidth 10 kHz. The higher noise level of the output signal does not interfere here since the phase-lock circuit has a very small bandwidth for synchronization of the VCO III.

The second FM-demodulator offers the possibility of switching one part of the receiver outputs and the control loudspeaker with switch S5 to the demodulator without the supporting circuit if the presence of the 2.4-kHz standard signals interferes during tuning of the receiver.

The VCO III (like VCO I and VCO II) is an astable multivibrator and supplies a rectangular voltage for controlling push-pull mixers 7, 8, and 9. Therewith these push-pull mixers also supply an output voltage if they are controlled with interference signals whose frequency is an uneven multiple of 2.4 kHz. Therefore the input signal for push-pull mixers 7, 8, and 9 is filtered in each case with an active low-pass filter. The frequency response of the active low-pass filter in the transmission band up to 3.6 kHz is designed so that the frequency response of the following push-pull mixer is compensated (Fig. 7a). Fig. 7 shows the frequency response of the low-pass filter on board VI M; the other two low-pass filters on boards V M and VII M possess similar frequency responses.

Fig. 7. Frequency response of the AF-amplifier with active low-pass filter. a: output 3d; b: output 1 to 3a.

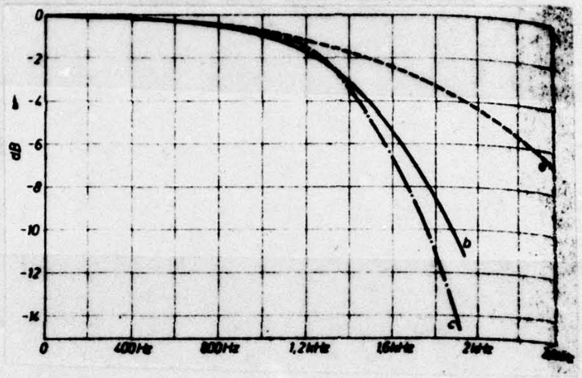


The standard voltage for VCO I should be a 2.4-kHz sine-wave voltage, and therefore a band-pass filter is required between the VCO III and the modulator. The additional phase shifter before the modulator serves for correcting the phase of the standard voltage.

AM-Coherent Demodulator for the Video Signal

A coherent demodulation of the amplitude-modulated subcarrier for production of the brightness signal for the telerecording equipment likewise results in a better signal-to-noise ratio than a demodulation of the subcarrier with the envelope demodulator present in many telerecording devices. Since the 2.4-kHz reference signal necessary for a coherent demodulation was already present in the receiver it was an easy matter to provide a subcarrier demodulator for the output signal (board U III M). The output signal of the FM-demodulator 1 (control voltage from VCO I) is provided through an active low-pass filter to the push-pull mixer 9 which is likewise controlled by VCO III. In addition to the brightness signal in the frequency range from zero to approximately 1.2 kHz the output signal also contains the remainder of the 2.4-kHz subcarrier frequency and, with a rather great amplitude, the sum of the input frequency and the VCO frequency. These unwanted frequencies are suppressed by an active low-pass filter (frequency response see Fig. 8).

Fig. 8. Frequency response of the subcarrier demodulator for the AM-subcarrier 2.4 kHz. a: GM 9; b: GM 9 and output low-pass filter (output 3b); c: GM 9 with FM-demodulator 1.



The subcarrier demodulator has two outputs. The second output (receiver output 3c) is designed specially for controlling the tube output stage in the photo recorder SU-type "NEWA," while the first output (receiver output 3b) has the same level as the subcarrier demodulator used in the telerecorder BAG 1.

AF-Final Stages and Outputs

For the outputs 1 to 3a a low-ohm output is realized through an emitter follower as a final stage. The input of this stage can be switched to FM-demodulator 2 with switch S 5. In both cases the output signal of the corresponding FM-demodulator runs through the attendant active low-pass filter.

The output of the FM-demodulator 1 (after passing through the low-pass filter) is sent separately to receiver output 3d. At this output the video recorder BAG 1 can be connected since in the video recorder a similar subcarrier demodulator is used. The control loudspeaker is also connected to the final stage for outputs 1 to 3a through the volume control P 1 and the AF-output amplfier (board VI M).

The Operating Voltage for the Components

The components of the receiver require stabilized supply voltages of -12 V and +12 V. When the receiver is connected the positive voltage should not reach its nominal value before the negative since otherwise the oscillation of VCO I and VCO II is not ensured. Therefore both operating voltages are derived from a stabilized 24-V voltage of a statron network component NB 750/24 by division using an electronic voltage divider (on board VII M). The electronic divider can stabilize a current distribution change of about +- 30 mA. Above that, e.g., through failure or removal of individual components of the receiver, it leads to a change of the voltage distribution. With the removal of board VII M the power supply of the remaining components of the receiver is interrupted.

With the creation of this receiver a modern, highly sensitive weather picture system became possible which permits recording of high-quality satellite weather pictures without a directed antenna. As proof of the high quality are two pictures produced with the installation. In the lower right portion Fig. 11 shows the snowstorm on 11 March 1971 over central Europe. In the top right Scandanavia can easily be recognized, the black surfaces are sea areas without cloud cover. The whirling character of the large storm can be easily recognized.

Fig. 12 was recorded on 5 May 1971 and shows the Sahara with the Nile delta, Suez Canal, and the Red Sea. The regular black and white dotted strips passing across the picture are noise breaks. They result with a low elevation angle of the satellite as a result of the unfavorable position of the transmitting antenna with respect to the fixed receiving antenna. By connecting a third channel with a vertical antenna they could be largely eliminated.

The device which was recently developed in a socialistic cooperative effort represents a totally new system solution which aroused great interest both here and abroad at the Leipzig Spring Fair 1971.

Technical Data

Operating mode:

Reception of signals which are frequency modulated with a 2.4-kHz subcarrier, whereby the subcarrier itself is amplitude modulated. The maximum processable frequency deviation of the carrier is 10 kHz.

Receiving range:

Telemetry band from 135.5 MHz to 138.0 MHz.

Circuitry:

Two-channel double superhet with automatic phase synchronization of the signals of both channels and the addition of the signals of both channels according to the optimum signal-to-noise ratio

First IF-frequency 10.7 MHz

Second IF-frequency 450 kHz

IF-bandwidth:

(magnetomechanical filter ind the 450-kHz-IF) 35 kHz

Demodulation principle:

Phase-lock demodulator with subcarrier support circuit

Input:

2x50 Ω coaxial

Antennas:

Two linearly polarized antennas (e.g. dipoles) with polarization directions arranged orthogonally to each other.

Input sensitivity:

With antenna amplifiers (2.5 kT_0) = $1 \cdot 10^{-15}$ W (total signal power of both antennas)

Image rejection:

better than 60 dB

At outputs 1 to 3a one obtains:

The modulated subcarrier with a level of 1 V for a frequency deviation of 10 kHz (switchable to FM-demodulator 2 without support circuit.)

3b and 3c:

The signal produced by demodulation of the subcarrier with the level between 0 and 6.5 V on 3b and between -12 V and -26 V on 3c corresponding to a frequency deviation between 0 and 10 kHz.

3d:

The modulated subcarrier with a level of 1.4 V for a frequency deviation of 10 kHz (raising of the low frequencies)

Frequency responses:

See Fig. 8 and Fig. 9.

Output resistance of the outputs in Ω:

1 to 3a ~ 100

3b ~ 500

3c ~ 10k

3d ~ 200

Minimum load resistance for the outputs in kΩ:

1 to 3a ~ 1 3b ~ 10

3c ~ 50

3d ~ 2

Frequency range:

Output 1 to 3a and 3d: see Fig. 9.

Output 3b and 3c: see Fig. 8, curve c

Power supply:

Mains connection	220 V/50 Hz
Power consumption	about 25 W
permissible mains fluctuations	+ 10 °/o, -20 °/o

Dimensions:

534 mm x 348 mm x 263 mm

Weight:

20 kg.

9. Frequency response for the AM-subcarrier 2.4 kHz for FM-demodulator 1. a: output 1 to 3a; b: output 3d; c: FM-demodulator 2.

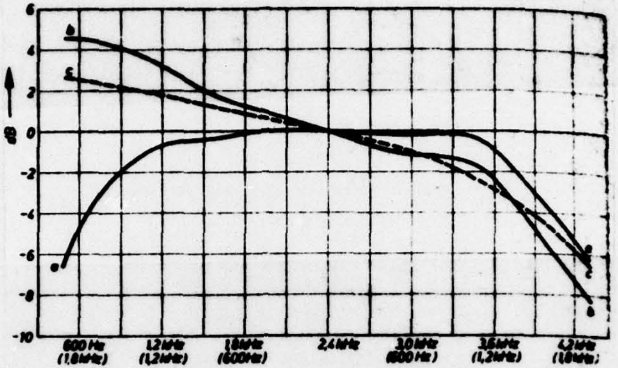


Fig. 10. ZEA 1 receiver.

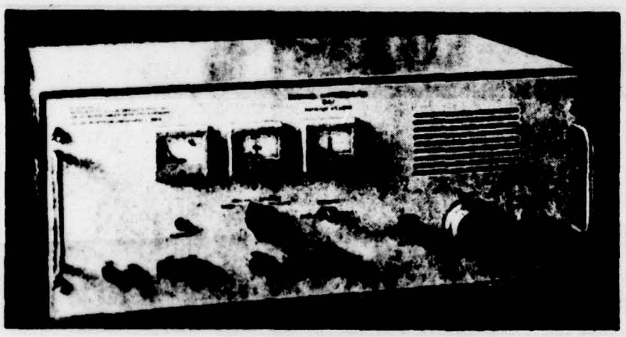


Fig. 11. Snowstorm over Europe on 11 March 1971.

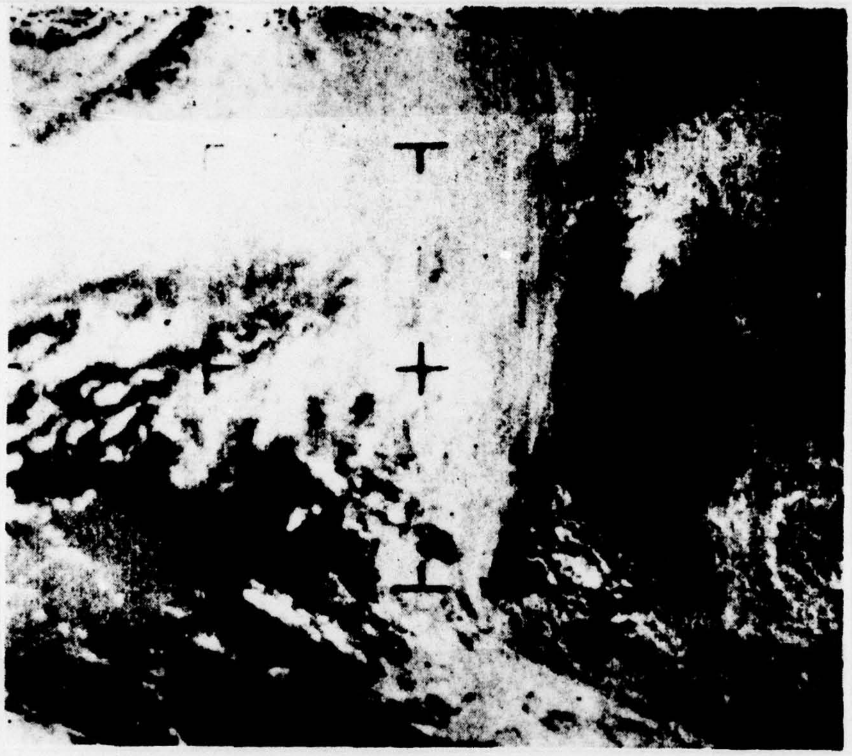


Fig. 12. Sahara area with Nile delta, Suez Canal and Red Sea recorded in the Central Institute for Solar-Terrestrial Physics on 5 May 1971 at 14.45 MET.

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