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NGU TFEM.
A Time- and Frequency-domain ElectroMagnetic instrument.
SYSTEM DOCUMENTATION

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RAPPORT

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The report introduces the NGU TFEM time- and frequency-domain electromagnetic system developed at the Geological Survey of Norway. A generel description of the system design, and a more specific description of the receiver-coil system, the receiver, the transmitter and the power supply units is given. The report does not include details of the theory, the hardwares and the programs.

This report was compiled after some improvements at the system made in 1987, and it replaces an earlier documentation (NGU Report 86.164).

Emneord	Elektromagnetisk måling	
Geofysikk	Systemdokumentasjon	
Instrument		

PREFACE

This report introduces the NGUTFEM time- & frequency- domain electromagnetic system developed in the Geological Survey of Norway (NGU). This project was started in 1982. From June to October in 1985 it was tested seven times over a near surface conductor at Tempervoll, Trondheim and twice over a deeply buried conductor at Kongsvoll. In 1986 the system was tested with good results in three different mineing areas in Norway, and after some improvements the final tests were made in Joma and at Kongsvoll in 1987.

This project was started by Per Eidsvig and Inge Vivaas. Bin Qian joined in the project in May 1983 and Kaare Høy in August 1984 when Vivaas quitted.

Per Eidsvig, the project manager in the first two and half years, was in charge of the whole system. Among other things, he developed the first model transmitter, wrote some calculation and monitoring programs for the receiver, and collaborated with Qian on the receiver-coil system. Inge Vivaas worked on the digital part of the receiver, which includes data storage in a Bubble memory, clock circuit, multiply/divide units, key board and display, and the related programs and computer work, etc. Bin Qian worked on the data acquisition part of the receiver, the related control circuits and the main program and subroutines of the receiver. When Eidsvig quitted in May 1985, Qian took over to adapt Eidsvig and Vivaas's work to the system, and developed the second model transmitter and a switching-type power supply unit, collabarated with Høy. Qian quitted in November 1985. Kaare Høy did most assembling work of the coil system, the receiver and the first-model transmitter, some programming work, and all the hardware work of the power supply unit and the second model transmitter. He also made the spare cards for the system. In 1987 Bin Qian came back to Norway to do some inprovements on the system, and as a result of this the hole measuring cycle was was reprogrammed. During 1986 and 1987 the system was tested with great sucsess in some mineing areas in Norway.

The boxes of the instruments, the frame of the coil system, the Helmholtz coil, etc., were made in the workshop of NGU. Many individuals in NGU and NTH helped with the development, field testing and data processing work of the project.

Geological Survey of Norway
November 1987

Bin Qian   Jan S. Rønning

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I. INTRODUCTION

1.1 The NGUTFEM system

The NGUTFEM system is a time- & frequency- domain electromagnetic prospecting system. It consists of seven parts: transmitter, power supply unit, generator, transmitter loop or grounded cable, receiver with separated battery pack, receiver - coil system, and a station computer. The power supply unit converts the 220 V AC power from the generator into a DC source. The transmitter sends strong current pulses into the large fixed transmitter loop or the grounded cable, and thus sets up an on-off type of primary field as shown in fig.1-1A. Each transmitter pulse has a quickly ended trailing edge. If there is any conductor in the adjacent area of the transmitter loop, an eddy current (fig.1-1B) will be induced in the conductor. The eddy current will further induce secondary field emf's (fig.1-1C) in the receiver-coil system nearby. The receiver samples the primary and secondary field signals by a number of channels and averages the samples over many transmitting cycles to raise the S/N ratio. The measured data are stored in a 1 mega-bit Bubble memory and later transfered to the station computer, for mass data storage and data processing.

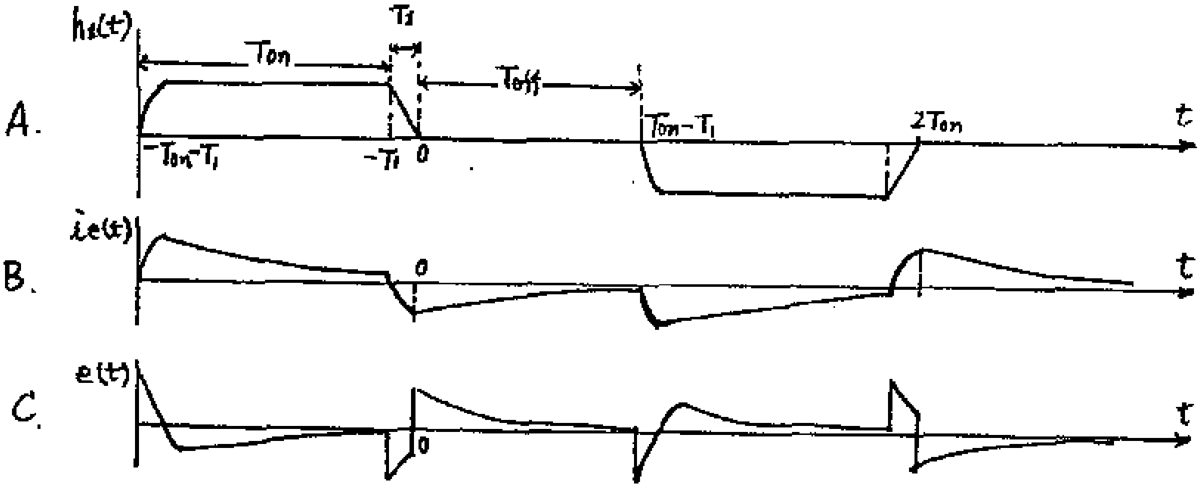

Fig.1-1 A) Primary field waveform. B) Eddy current.
C) Secondary field emf induced in a receiver coil.

The NGUTFEM system measures the primary and secondary fields in both time and frequency domain simultaneously. Primarily it is a TDEM system. As the transmission is pulsed, pure secondary field measurement can be realized at the total absence of the primary field during the transmitter-off time (Toff, fig.1-1), thus the influence of the primary field is removed. The investigation depth can be greatly increased by using high transmitter power. This is the essential characteristic of the TDEM measurement using an on-off type of primary field waveform.

Being a periodic signal, the primary field is very rich in harmonics:

$$h1(t)= \sum_{n=1,3...} Cn*Sin(2Pi*n*f1*t+pn)$$

where Cn and pn are the amplitude and phase of the n-th harmonic component, f1 is the fundamental frequency of the primary field waveform. For the NGUTFEM system f1=25Hz. In theory, a TDEM system is equivalent to a multifrequency EM system. It is suitable for detecting a wide variety of conductors. This is another important feature of the TDEM measurement.

If the target conductor has a very long time constant, a TDEM system may fail to detect it (see Sect.2.2). Being also a frequency-domain system, the NGUTFEM has two frequency-domain channels measuring the fundamental-frequency component of the vertical field. This measurement helps to reduce the danger of missing conductors with long time constant.

Statistic calculation is carried out during the measurement to estimate the data quality and to suppress strong interferences.

The system measures two spatial magnetic components simultaneously, so as to acquire more information about the geometry of the target in one attempt. Each spatial component is sampled by 8 time-domain (TD) channels.

With only 15 Kg to carry between measurement stations on surface traverses, the receiver-coil system and the receiver were designed for one - man operation.

1.2 Important features

A). Real time statistic calculation to optimize the data, to ensure the desired quality of data and to speed up the measurement.
B). Simultaneous measurements in time and frequency domain.
C). Simultaneous measurements of two spatial components of the magnetic field.
D). High frequency coils for early channels and high sensitivity coils for later channels.

E). Full overflow control.
F). Safe, quick and power-saving data storage in Bubble memory.
G). Automatic scaling or manual setting of amplification.
H). Wide dynamic range and high resolution.
I). Instantaneous monitoring during measurement.
J). Water-proof and light-weighted receiver and coil system.
K). PROM selectable sampling arrangement.
L). Wireless crystal clock synchronization.
M). Anolog output for modelling purpose.

1.3 Specifications

A). Coil system and Receiver

Weight

Receiver	4.2 Kg
Coil system	5.4 Kg
Tripod	1.6 Kg
Battery pack	3.2 Kg
Carrier of receiver and battery	0.8 Kg
Total	15.3Kg

Size

Receiver	28.5x18x24 cm
Battery pack	22x13x8 cm
Coil system	44x44x9 cm
Tripod	78x9x9 cm

Power supply 15v/7AH rechargable battery pack

Power consumption

off (oscillator and counter on)	130 mA
all on	400 mA

Sensitivity of coils

Low frequency coils	3.2uV/(nt.Hz)
High frequency coils	1.2uV/(nt.Hz)

Number of sampling channels 18

16 in time domain and 2 in frequency domain. Of the TD channels, two for Primary+Secondary field, 14 for secondary field. (7 for vertical and 7 for horisontal. Their locations can be skifted backwords by two steps to cover the whole time of the transient.)

Channel width 19.58 us--1250 us.

Amplification

Preamplifiers	x4,x16,x64,x256
Intermediate amplifiers	x1,x4,x16,x64 for TD channels x16,x512 for FD channels
Last amplifiers	x1,x4,x16,x64

Dynamic range

TD channels: 4**9   FD channels: 2*(4**8)

A/D converter: 12 bits

Resolution (nv)

Primary field channels:		74.5		
Secondary field channels	s1:	37.3	s2:	18.6
	s3:	18.6	s4:	9.31
	s5:	4.66	s6:	2.33
	s7:	1.16		
Frequency-domain channels:	0.29	(peak value)		

Maximum input   1.25V (peak value)

Temperature range   0 Deg.C.--?

Measuring time at each station: 32+ (NH-32)X0.56 sec.
NH:32--65535,selectable via key board. Default value: 100.

Data storage: 128 bytes stored in a 1 mega-bit bubble memory at each station.

Amplification setting

Automatic scaling for all amplifiers in 2 seconds, or
Manual setting via keyboard, or
remaining the previous amplifications.

Synchronization: oven-stabilized crystal oscillators keep synchronization (drift<10 us within 8 hours).

Data output

8-bit parallel and RS232 serial interfaces to computers:
8-character LCD on the panel;
One anolog output for laboratory modelling purpose. Channel selectable among V0--V7 via keyboard.

Frequency bandwidth (Limited by analog filters)

High frequency channels:	1.6Hz--10KHz;
Low frequency channels:	1.6Hz--3KHz;
Frequency-domain channels:	23-27Hz.

B). Transmitter

Weight   11 Kg

Size   40x36x22 cm

Input voltage	AC 220v for operation DC 10--220v for transmission
Output current	0.1--12.6A
Loop size	no limit
Loop resistance limit	1--2000 ohm
Pulse width	10 ms

Accuracy of displayed parameters	
Current	0.1 A
AC voltage	1 v (RMS)
DC voltage	1 v
Loop resistance	0.1 ohm
Synchronization	1 us
Width of trailing edge	1 us

C). Power supply unit

Weight	18 Kg
Size	40x36x22 cm
Input voltage	AC 220v (+/- 20%),50-400 Hz
Output voltage	DC 32--212v
Output current	6A (DC); 10A (pulsed,50% duty cycle) 12.6A(pulsed,output voltage<70V)
Output short-circuit protection	
High temperature protection	70 deg.c. on heat sink

II. FUNDAMENTALS OF SYSTEM DESIGN

2.1 Secondary field signals

The first pulse of the primary field waveform shown in fig.1-1A can be expressed as

$$h1(t)=[1-\exp(-t'/TL)]U(t')-(t''/T1)U(t'')+(t/T1)U(t)$$

where $t'=t+Ton+T1$, $t''=t+T1$, Ton is the duration of the transmitter on-time, T1 is the width of the trailing edge of the pulse, TL is the time constant of the transmitter loop, and $U(t+x)$ is a step function started from $t=-x$. The Laplace transformation of h1(t) is

$$H1(s)=[1/s-1/(s+1/TL)]\exp[(Ton+T1)s]-[\exp(T1*s)-1]/(T1*s*s)$$

For convenience of analysis, a single-turn conducting loop model with a self inductance L and a resistance r is used to simulate the target conductor (fig.2-1). Under the excitation of the primary field h1(t), an eddy current ie(t) is induced in the model and it further induces a secondary field emf e(t) in the receiver coil. Since the initial amplitude of h1(t) and consequently that of the eddy current in the model are zero, the secondary field emf induced in a receiver coil can be related to the primary field by

$$E(s)=K*S*S*H1(s)/[L(s+1/Tc)]$$

where $Tc(=L/r)$ is the time constant of the model, K is a geometrical coefficient. To concentrate on the question that how the resistance of the model affects the behavior of the secondary field, we vary only the resistance of the model and keep all the other parameters of the modeling system (size and shape of the model, geometry of the modeling system, transmitter power, etc.) unchanged, so that both K and L will be constants and can be omitted, and Tc will be inversely proportional to r.

The time function of E(s) is

$$e(t)=[A*\exp(-t'/TL)-B*\exp(-t'/Tc)]U(t')-C*\exp(-t''/Tc)U(t'')$$
$$+C*\exp(-t/Tc)U(t), \quad Tc\neq TL \tag{2-1}$$

or when $Tc=TL$, it becomes

$$e(t)=D*\exp(-t'/Tc)U(t')-C*\exp(-t''/Tc)U(t'')$$
$$+C*\exp(-t/Tc)U(t) \tag{2-1a}$$

where $B=1/(Tc-TL)$, $A=B*Tc/TL$, $C=1/T1$ and $D=(1-t'/Tc)/Tc$. A typical secondary field emf is shown in fig.1-1B. It has a complicated shape in the on-time.

If Tc and/or TL are comparable with or longer than Ton, influence of residuals of the secondary field excited by the preceding primary field pulses should be taken into consideration. Then in the off-time, the secondary field emf will be

$$e(t)=A*F(TL)\exp(-t'/TL)-F(Tc)[B*\exp(-t'/Tc)+C*\exp(-t''/Tc)$$

$$-C*\exp(-t/Tc)], \quad 0<t<(Ton-T1), \quad Tc\neq TL \tag{2-2}$$

where $F(x)=1/[1+\exp(-2Ton/x)]$. In most cases $TL<<Ton$, and later it will be proved that the system is not suitable for detecting conductors with $Tc>Ton$. For the purpose of calculating system parameters, we use a simplified and normalized expression of $e(t)$:

$$e(t)=G*\exp(-t/Tc), \quad 0<t<(Ton-T1) \tag{2-3}$$

where $G=1-\exp(-T1/Tc)$.

For the induced emf, the coil behaves exactly in the same way as a 2nd-order lowpass (LP) filter. The output of the coil is

$$U(s)=[Wn*Wn/(s*s+2d*Wn*s+Wn*Wn)]E(s)$$

where $Wn=2Pi*fn$, fn and d are the natural frequency and the damping coefficient of the coil, $Pi=3.14159$. Under the condition that $TL<<Ton$, the time function of $U(s)$ in the transmitter off-time can be expressed as

$$u(t)=H*e(t)+I*\exp(-d*Wn*t)=u1(t)+u2(t), \quad 0<t<(Ton-T1) \tag{2-4}$$

where $u1(t)=H*e(t)$, $u2(t)=I*\exp(-d*Wn*t)$, I is a function of time (expression omitted), and

$$H=Wn*Wn/[Wn*Wn+1/(Tc*Tc)-2d*Wn/Tc].$$

There is an AC coupling capacitor in each of the four linear circuit channels of the receiver. This capacitor, together with the input impedance of its following circuit, forms a 1st-order highpass (HP) filter. While considering the HP filter response, we assume that fn is high enough so that the transfer function of the coil is essentially 1. Then the response of the HP filter is

$$Uh(s)=[s/(s+2Pi*fh)]U(s)-[s/(s+2Pi*fh)]E(s)$$

where fh is the lower cut-off frequency of the HP filter. In the off-time, the time function of $Uh(s)$ is

$$uh(t)=J*e(t)+K*\exp(-2Pi*fh*t)=uh1(t)+uh2(t), \quad 0<t<(Ton-T1), \tag{2-5}$$

where $uh1(t)=J*e(t)$, $uh2(t)=K*\exp(-2Pi*fh*t)$. J and K are functions of Tc, fh, T1 and Ton (expressions omitted).

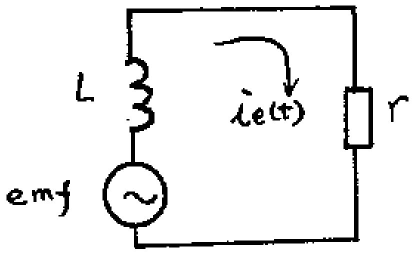

Fig.2-1 Conducting loop model of a conductor.
emf: induced electromotive force.
ie(t):eddy current.

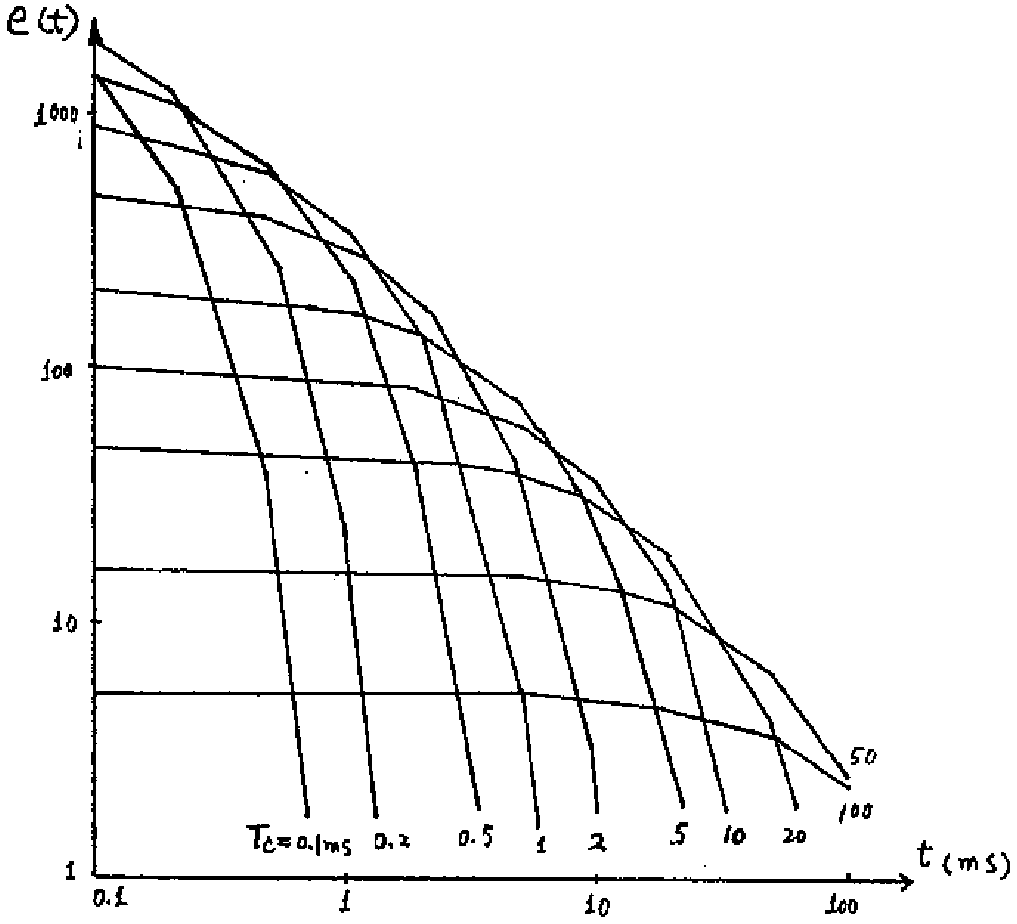

Fig.2-2 Secondary transient emf in the off-time.
Ton=100ms, T1=0.2ms.

2.2 Parameters of the primary field waveform

Primary field waveform as shown in fig.1-1A was adopted by the NGUTFEM because of the following advantages of the waveform: 1, pure secondary field measurement can be realized: 2, this waveform is suitable for exiting a wide range of conductors: 3, it is easy to generate; 4, there is almost no limit on the transmitter loop size and shape; 5, high transmitter power can be conveniently applied.

Once the shape of the waveform is decided, there are only four parameters to be selected: the transmitter on-time (Ton), the width of the trailing edge (T1), the amplitude of current, and the rising rate of the leading edge. The rising rate of the leading edge only depends on the loop inductance and resistance. It has little influence on the measurement. The current is limited to within 12.6A for the prototype and it can be easily raised in a new design. Selections of Ton and T1 are more closely related to the properties of the targets.

Figure 2-2 shows a group of e(t) curves in the off-time computed according to eq.(2-2). Although e(t)'s with different Tc's have different initial amplitudes, there exists a time slot for each e(t) where it is at a maximum relative to all the others. And for any e(t) with a Tc within the range (T1, Ton-T1), its corresponding time slot is located at t=Tc. Therefore, e(t)'s with their Tc's within (T1,Ton-T1) will get fairly equal chance to be detected despite of the difference of the initial amplitudes, if the noise level is low enough. On the other hand, conductors with their Tc's out of this range (T1, Ton-T1) will get little chance to be detected, or in other words, a TDEM system is not suitable for detecting conductors with their Tc's out of the range (T1, Ton-T1). T1 and Ton should be selected deliberately to meet the prospecting purpose.

When selecting T1, the following factors should be taken into consideration:

A). Conducting overburdens and poor conductors often have short Tc's. For mapping purpose, T1 may need to be short. While for detecting big and good conductors, T1 should be long enough to suppress the responses from overburdens.

B). Shorter T1 will lead to higher peak value of emf during the trailing edge time, and therefore, wider dynamic range of the receiver is required.

C). The primary field is sampled in the last 20 us during the trailing edge time, so T1 should not be too short.

D). For the NGUTFEM system, the delay time of the first channel from the end of the trailing edge is about 140 us. T1 needs not to be shorter than this value, not even for the mapping purpose.

E). T1 should not be longer than 2.5ms, or the last channel S7 will fall into the transmitter on-time.

In practice, a T1 value in the range (100us, 1000us) is relevant.

T1 can be found by the approximative formula:

$T1=2Vt*L/[R(Vt+2Vz)]$, $Vt<5Vz$

where L and R are the inductance and resistance of the transmitter loop, Vt is the transmitting voltage and Vz is the total zener voltage of the zener diodes in the transmitting network . Vz is about 110v for the presently used diodes. It can be any value between 20v and 200v. When using a grounded cable, an extra air-cored inductance can be put in series with the cable for proper length of T1. The real value of T1 is read from the transmitter during transmission.

For the NGUTFEM system, Ton is fixed to 10ms. This was a result of a compromise of the following considerations: target conductors to be detected, suppression to the 50Hz power-line interference, total stacking time needed at each station, etc. Ton can be varied by a few changes in receiver and transmitter if necessary.

2.3 Frequency bandwidth of the receiver system

The primary and secondary field signals are periodic pulse sequences which are rich in harmonics. To prevent the signals from being seriously distorted, the receiver system, which consists of the receiver coils and the receiver, must have a wide frequency bandwidth. This bandwidth is actually limited by the natural frequency (fn)of the receiver coil.

A). Natural frequency of receiver coils

u(t) defined by eq.(2-4) consists of two parts, u1(t) and u2(t). u1(t) is the forced oscillation of the coil due to e(t) and proportional to e(t), and therefore the signal to be measured. u2(t) is the free oscillation of the coil, behaving as an interferer. If fn is high, u2(t) dies out after a short time, we call it recovery time Tr. But at the beginning of the transient it has strong influence over the measurement of u1(t). Fig.2-3 shows some curves of e(t) and u(t). u(t) with fn=10KHz (curve 3) agrees well with e(t) (curve 1) after a recovery time, Tr, of about 160us.
If fn=30KHz, Tr is only 60us. But if fn=3KHz, it will be 500us. Tr is actually the time needed for u2(t) to decay to a negligible level relative to u1(t), i.e.:

$$u2(Tr)=Er*u1(Tr) \qquad (2-6)$$

where Er is the acceptable relative error.

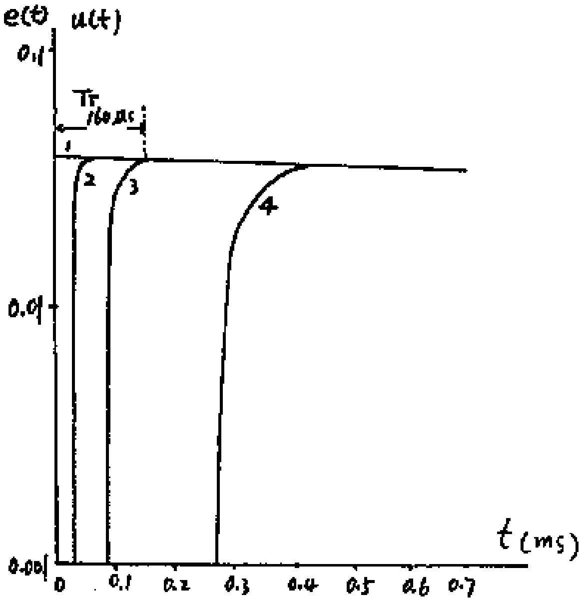

Fig.2-3 e(t) and u(t) curves in the off-time. Tc=5ms. 1) e(t). 2) u(t), fn=30KHz. 3) u(t), fn=10KHz. 4) u(t), fn=3KHz.

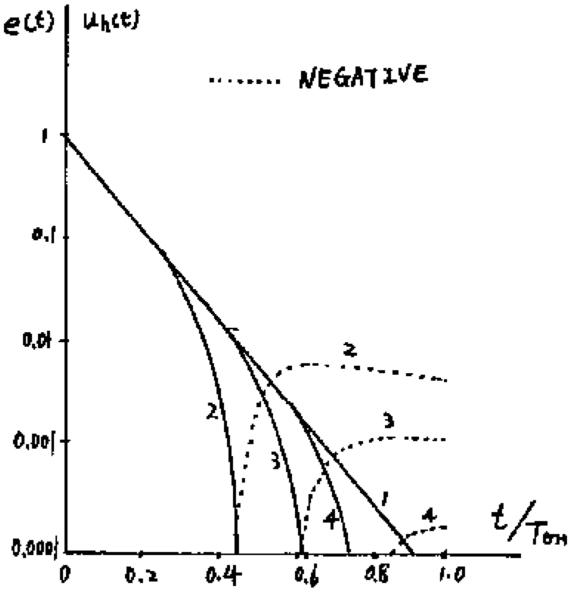

Fig.2-4 e(t) and uh(t) curves in the off-time. Tc=0.1Ton. 1) e(t). 2) uh(t), fh=f1. 3) uh(t), fh=0.5f1. 4) uh(t) fh=0.25f1. f1=(1/4Ton)=25Hz.

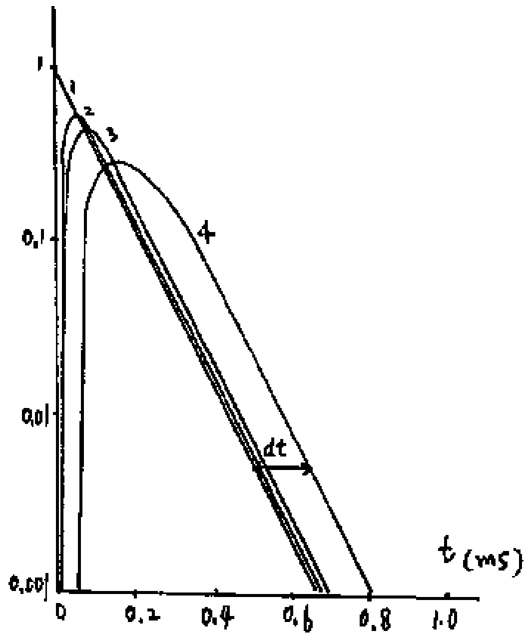

Fig.2-5 e(t) and u(t) curves in the off-time. Tc=0.1ms. 1) e(t). 2) u(t), fn=30KHz. 3) u(t), fn=10KHz. 4) u(t), fn=3KHz.

If the receiver starts sampling the transient before the recovery time is passed, a rather erroneous result or false anomaly should be expected.

According to eqs.(2-4) and (2-6), an approximate formula is established:

$$fn \geq [1/(2Pi*d)]\{1/Tc-(1/Tr)Ln[Er-Er*exp(-T1/Tc)]\} \qquad (2-7)$$

This formula can be used to calculate fn according to the given conditions and demands for T1, Tc, Tr,d and Er. Here Tr should be replaced by Ts, which is the delay time of the center of the first sampling channel from the end of the trailing edge. For example, if d=1, Er=3%, T1=200us, Ts=140us and Tc ranges from 0.1ms to 5ms, fn=7.7KHz is the lowest acceptable value.

As LP filters are used in the receiver as well and they will cause errors in the same way as the receiver coil does, a little higher value of fn, 10KHz, was selected.

B). Lower cut-off frequency

Similar to u(t), the HP filter response uh(t) defined by eq.(2-5) also consists of 2 parts, uh1(t) and uh2(t). uh1(t) is the signal to be measured and uh2(t) behaves like an interferer. Fig.2-4 shows the e(t) and some uh(t) curves. In the later parts of the uh(t) curves the polarities were reversed. The maximal amplitudes of the negative values of curves 2 and 3 are approximately 0.6% and 0.12% of the initial amplitude of the transient. They are strong enough to be recorded by the receiver.

It has been proved that IP effects of some ore bodies in TDEM measurements can also result in polarity-reversed transients. Such polarity-reversed transients have similar shapes as those shown in fig.2-4. So IP effects of ore bodies and the HP filter effect in the receiver can both finally result in polarity-reversed transients in TDEM measurements. But their meanings are completely different. Those caused by IP effects carry important information of the ore bodies, while those by the HP filter effect are false anomalies and could lead to wrong conclusions. Therefore, the lower cut-off frequency of the receiver system should be low enough, so as to ensure that the distortions caused by the HP filter effect would be within some acceptable limits, and the measured data would really represent the true anomaly caused by the target. Calculations show that the maximal negative transient will be within 0.01% of the initial transient amplitude if the inequality

$$fh>f1/5$$

is satisfied. In case the order of the HP filter is higher than 1, the inequality should be replaced by:

$$fh<f1/(5n)$$

where n is the order of the HP filter.
For the NGUTFEM system, fh is 1.6Hz(=0.064f1). As the dynamic range of the system is tremendously wide, the polarity-reversed transient still can be observed clearly when a pure exponential calibration signal with a short Tc was fed into the receiver.

2.4 Higher sensitivity for later channels

In Sect.2.3 fn=10KHz was selected for a fast frequency response which is necessary for the early sampling channels. For the later ones, however, the frequency response is not so critical. As the transients are much weaker in the later time, higher sensitivity of the coil is more significant. Therefore, another coil with lower natural frequency but higher sensitivity was designed for the later channels (s4,s5,s6 and s7). The center of s4 is about 860us from the end of the trailing edge . Let Ts=860us, d=1, Er=3%, T1=200us and 0.1ms<Tc<5ms, fn should be higher than 1280Hz according to eq.(2-7). 3KHz was selected considering the possible errors caused by the LP filters in the receiver. This relatively lower fn means heavier suppression to high frequency interferences like VLF signals, and the sensitivity of the low-fn coil is 2.6 times of that of the high-fn one. Both are benefitial to the late-time measurement.

2.5. Normalization of measured data

Since two different coils were used to detect the early and later parts of the transient separately, the measured data must be normalized. This can be done in the data-processing programs in the station computer by multiplying the measured values of the early channels by 2.6, or by dividing the measured values of the later channel by 2.6. Neither of these two ways of normalization has been applied to the data stored in the Bubble memory. In the MON(itor) program of the receiver, the former way was adopted when the measured values should be displayed on LCD.

2.6. Correction of delay time

Another thing one should take care of is the delay effect of the coils. Fig.2-5 shows transient signals with Tc=100us. It is quite obvious that the u(t) signals have been delayed by the coils. Now even after a recovery time Tr (60us for fn=30KHz and so on) is passed, u(t) still cannot stand for e(t). As a result of the delay effect, the actually measured values will be larger than what they should be. The relative error caused by the delay effect of the coil is defined as:

$$ER=[u(t)/e(t)-1]*100\%, \qquad t>Tr.$$

Some calculated values are given in Table II-1. There we see that to keep the error within 10%, fn should be higher than 30KHz to measure transients with small time constant. This high fn will cause two problems: one is that for the same kind of receiver coil, higher natural frequency means lower sensitivity. Another is that higher natural frequency leaves more chances for noises and external interferences, such as VLF broadcasting, static noise ,etc. These two factors together will to some extent reduce the signal-to-noise ratio.

Table II-1. Error caused by delay effect of the receiver coil (%)

fn(KHz)	Tc(ms)			
	0.1	0.2	1.0	5.0
3	320.5	83.0	10.7	-0.2
10	41.4	18.0	3.3	0.6
30	11.5	5.5	1.1	0.2

In fig.2-5, after a necessary recovery time Tr, all the u(t) curves are parallel to the e(t) curve. In other words, when t>Tr, the difference between e(t) and u(t) is only a delay time dt. Then we have:

$$u(t)=e(t-dt), \quad t>Tr. \qquad (2\text{-}8)$$

This equation tells us how to correct the error caused by the delay effect of the coil, that is, to take a measured value at time t as the e(t) value at time (t-dt). It is simple. No changes in the instrument or coil are needed.

To apply this correction, dt must be estimated. In eq.(2-4), when t>Tr, the second part is small enough to be ignored, then:

$$u(t)=H*e(t), \quad t>Tr. \qquad (2\text{-}9)$$

From eqs.(2-8) and (2-9), we get:

$$dt=2Tc*Ln(Wn)-Tc*Ln[Wn*Wn+1/(Tc*Tc)-2d*Wn/Tc]. \qquad (2\text{-}10)$$

To achieve the best correction, the dt value calculated for small Tc should be used because transients with small Tc are more sensitive to time changes. Table II-2 shows the relative errors left after applying the correction of delay time. The error is defined by:

$$ERc=[u(t)/e(t-dtmax)-1]*100\%$$

where dtmax is the dt value calculated for Tc=100us. For fn equal to or higher than 10KHz, the correction is exact.

Delay time caused by LP filters in the receiver should also be corrected. The total delay time is a sum of that by the coil and those by the LP filters:

$$dt=\sum_i dti$$

Fourth-order Butterworth LP filter were used in the receiver to suppress the VLF interferences. This filter is actually two 2nd-order LP filters in series with damping coefficients d1=0.38 and d2=0.92. The damping coefficient d is 0.86 for high-fn coils and about 1 for low-fn ones. Eq.(2-10) can be directly used to calculate the individual delay time caused by each of them. The higher cut-off frequency of the LP filter is equal to the natural frequency of the corresponding receiver coil. The total delay time is calculated to be about 70us for the early channels and about 283us for the later channels.

A little bigger value of dt should be used because the other circuits , such as the preamplifers, also have some delay effect. We take dt=80us for the early channels, and dt=330us for the later channels including the delay time caused by the 5KHz 1st-order LP filter in the low frequency preamplifier (fig.3-2). The last column in Table II-3 shows the centers of the sampling channels after the correction has been applied.

Table II-2. Error left after applying the correction (%)

fn(KHz)	Tc (in ms) 0.1	 0.2	 1.0	 5.0
3	-0.2	-13.0	-4.1	-0.9
10	0.0	-0.8	-0.3	0.0
30	0.0	-0.1	0.0	0.0

2.7 Channel arrangement

To find the initial amplitude G and the time constant Tc of a pure exponential transient as expressed by eq.(2-3), two samples of the transient at two different delay times is enough:

$$Tc=(t2-t1)/[Ln(S1)-Ln(S2)] \qquad (2\text{-}11)$$

$$G=S1*\{(S1/S2)**[t1/(t2-t1)]\} \qquad (2\text{-}12)$$

where S1=e(t1) and S2=e(t2). Usually, the secondary transient is a combination of many pure exponential transients as follows

$$e(t)=\sum_j ej(t) \ .$$

To figure the combined transient to details, a big number of samples are obligatory. For each pair of adjacent samples, an apparent time constant and an initial amplitude can be found according to eqs.(2-11) and (2-12). Due to practical considerations of data quantity and necessity, the NGUTFEM was designed to sample the secondary transients in seven time intervals (channels). It also samples the primary field during the trailing edge time of the transmitter pulse. Fig.2-6 shows the eight sampling channels.

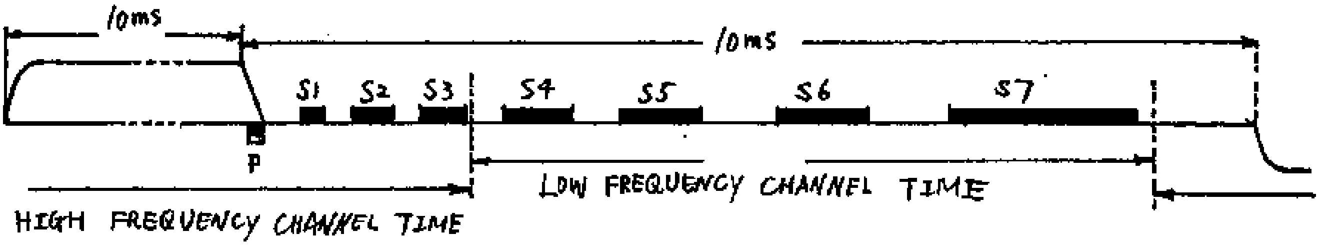

Fig.2-6 Sampling channels (not to the scale). P: primary field channel. S1-S7: secondary field channels.

The system measures two spatial magnetic components in the same time. It has 16 channels working in time-domain. In addition, it has another two time-sharing channels working in frequency domain. Fig.2-7 shows the relations between the channels and the coils, and Table II-3 lists the specifications of the channels. channels. FHH/FLH are high/low fn, horizontal coils and FHV/FLV are high/low fn, vertical coils.

Table II-3. Channel specifications (relative to the end of the trailing edge of the primary pulse)

(us)

channel	from	to	width	center	center*
H0,V0 (P)	-19.58	0	19.58	-9.79	/
H1,V1 (s1)	116.2	156.3	39.1	136.7	56.7
H2,V2 (s2)	234.4	312.5	78.1	273.5	193.5
H3,V3 (s3)	390.7	468.8	78.1	429.7	349.7
H4,V4 (s4)	781.3	937.5	156.3	859.4	529.4
H5,V5 (s5)	1562.5	1875.0	312.5	1718.8	1388.8
H6,V6 (s6)	3125.0	3750	625	3437.6	3107.6
H7,V7 (s7)	6250	7500	1250	6875	6545
V8,V9	/	/	20000*6	/	/

* Centers of the channels after the correction of delay time is applied.

	GROUP 1				GROUP 2				GROUP 3				
Channel	From	To	Centre	Centre$^+$	From	To	Centre	Centre$^+$	From	To	Centre	Centre$^+$	Channel width
VO, HO	-19.53	0.0	-9.77	-	-19.53	0.0	-9.77	-	-19.53	0.0	-9.77	-	19.5
1	117.185	156.25	136.7	56.7	195.315	234.38	214.9	134.9	273.435	312.5	293.0	213.0	39.0
2	312.5	390.625	351.6	271.6	390.625	468.75	429.7	349.7	468.75	546.875	507.8	427.8	78.12
3	546.875	625.0	585.9	505.9	625.0	703.125	664.1	584.1	703.125	781.25	742.2	662.2	78.12
4	781.25	937.5	859.4	529.4	1093.75	1250.0	1171.9	841.9	1406.25	1562.5	1484.4	1154.4	156.2
5	1562.5	1875.0	1718.8	1388.8	2187.5	2500.0	2343.8	2013.8	2812.5	3125.0	2968.8	2638.8	312.5
6	3125.0	3750.0	3437.6	3107.6	4375.0	5000.0	4687.5	4357.5	5625.0	6250.0	5937.5	5607.5	625
7	6250.0	7500.0	6875	6545	7500.0	8750.0	8125	7795	8750	9375	9062.5	8732.5	1250* 625**

Table II-4.

New channel Arrangement

* for Group 1 and 2

** for Group 3

\+ Centre of the channel after Delay Time Correction is applied (see system Documentation § 2.6). For chanels 1, 2, 3, Centre$^+$ = Centre -80. For channels 4, 5, 6 and 7, Centre$^+$ = Centre -330.

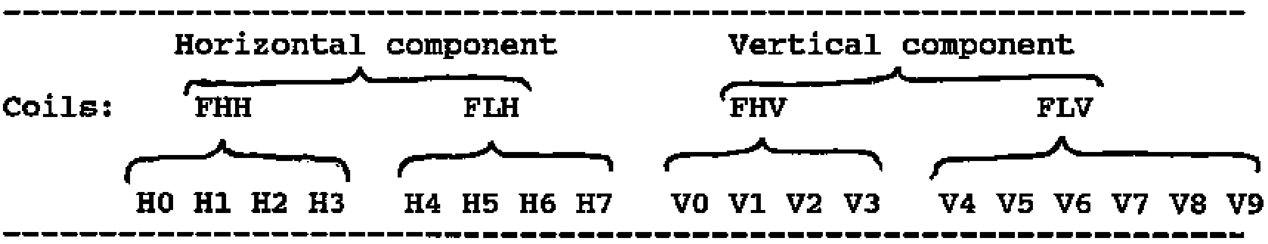

Fig.2-7. Relationship between coils and sampling channels.

In 1987, the program has been changed to enable more detailed sampling of the secondary transient. The channels V1-V7 and H1-H7 can be shifted backwords by two steps, so that the transient can be sampled by essentially 21 channels. The shifting is done by answer one question before scaling (see users'manual) The new arrangement of the channels is listed in Table II-4. Note that in Group 3, the width of the seventh channel is half of those in Group 1 or 2.This means that the integration time is only half of what it should be. As a result, the reading of the 7-th channel in Group 3 is halfened. In the later processing programs, the value of the 7-th Group 3 should be doubled to get the correct value.
The information of the Group is stored in the bubble together with all the other data after each measurement. The 125-th byte keeps the number of Group (1 for Group 1,2 for Group 2 and 3 for Group 3.)

2-8.Frequency-domain measurement

From Sect.2.2 we know that a TDEM system may fail to detect conductors with very long time constants. This danger is reduced by the ability of measuring the primary field. In addition to this, the NGUTFEM measures two components of the fundamental frequency (25Hz) of the vertical field to ensure that no good conductors will be missed.

The 25Hz signal measurement is accomplished by applying analogue filtering, synchronized detection, multi-cycle averaging and real-time data optimisation techniques.

The two components, V8 and V9, are not exactly Re and Im components because the phase will change if the configuration varies. In practice, the initial phases of V8 and V9 can be found by measuring close to the loop. These initial phases are taken as references for the later measurements.

V8 is close to the real component and V9 is close to imaginary component of the fundamental frequency of the primary field.

2.9 Amplification and dynamic range

In order to follow a flat anomaly caused by a deeply buried conductor, the measurement may have to be made from inside the transmitter loop to places kilometers away from it. The TDEM measurement, therefore, implies requirements for a large amplification and wide dynamic range in the instrumentation. A resolution of about 1 nv for the latest channels (H7 and V7) was claimed. To bring this weak signal up to 2.44mv which is the equivalence of one bit of the A/D convertor output, an amplification of more than two million is required.

The integrators I1 and I2 have a gain of 2 for the latest channels, so the total amplification of the amplifiers should be more than one million. This total amplification is realized by three stages of amplifiers: the preamplifier, the intermediate amplifier and the last amplifier, each with a dynamic range of 4**3. The total dynamic range is 4**9 for the time-domain channels and 2*(4**8) for the frequency-domain channels. In the field, a proper amplification is selected and distributed to the three stages by the microprocessor according to the signal and noise level.
As a result of the large amplification and wide dynamic range, the resolution is 1.16nv for the latest channels and 0.29nv for the frequency-domain channels, and the input can be as high as 1.25v (peak value) which means measuring 2 meters away from the transmitter cable carrying a current of 5 A with T1=200us and $TL \geq T1$, or 2.6 meters away from a 50Hz power line with a current of 100A flowing through it.

The formulas used to calculate the above distances are:

$B = uo * I/(2\, pi * r)$ and $e = B * S/2pi * TI$ (for transmitter cable)

or

$e = B * S * f$ (for 50Hz power line).

where B is the magnetic induction, I is the current, r is the distance from the cable to the receiver coil, e is the induced emf in the coil, S is the sensitivity of the coil (see the next chapter), and f is the frequency of the current.

III. RECEIVER-COIL SYSTEM

3.1 Configuration

As some of the special features, the NGUTFEM system measures two spatial magnetic components at the same time, and it uses two coils for each spatial component to meet the separate demands for sensitivity and frequency response of the early and late channels. The coil system, therefore, consists of 4 ferrite cored receiver coils, each followed by a preamplifier (Fig.3-1).
A Faraday shielding layer is attached from the outer surface of the frame which holds the 4 coils rigidly in position. The cores and the shieldings are connected to the common of the receiver to eliminate electrical interferences.

3.2 Calibration

The sensitivities and natural frequencies of the coils were calibrated with the help of a two-turn Helmholtz coil which has a resonance frequency of 5 MHz. At the center of the Helmholtz coil, the magnetic-induction caused by a unit current is

$$K=B/I=8*uo/(\sqrt{125}*a)=8.992*[10**(-7)] \quad [Tesla/Ampere]$$

where a(=1M) is the radius of the Helmholtz coil which equals to the distance between the two layers, uo=4pi*10**(-7), B is the magnetic induction, I is the current flowing through the Helmholtz coil. K was checked by sending a DC current through the Helmholtz coil and measuring the incremental magnetic field by a magnetometer, the error was within 1% .

An AC current was sent into the Helmholtz coil and the induced emf in the receiver coil, which was placed at the center of the Helmholtz coil and was coaxial with it, was measured. The sensitivity of the receiver coil was found by the formula

$$S=e/(B*f)=e/(K*I*f) \quad [v/(Tesla.Hz)]$$

where e is the emf induced in the coil, f is the frequency of the AC current. For calibration of sensitivity, f should be far lower than the natural frequency fn of the coil to be calibrated. f=0.1fn is often adopted.

Normally the receiver coil has a high Q value, so fn can be found simply by increasing f until the emf induced in the receiver coil reaches its maximum.

The capacitance Co of the coil is approximately

$$Co \sim 1/(Wn*Wn*L) \ .$$

The coil must be damped by a resistor to get a flat frequency response around fn when it is used as a receiver coil. The damping coefficient of the coil is approximately

$d=\sqrt{L/Co}/(2R)$

where R is the damping resistance in parallel with the coil. It was found that $d\approx 0.9$ is a good damping state for TDEM measurement (derivation omitted).

Parameters of the four receiver coils are given in Table III-1.

Table III-1. Parameters of the receiver coils

Coil	N	S	fn	L	Co	ro	R	d
FHH	7500	1,2	10	9.0	28	1.5	330	0.86
FHV	7500	1,2	10	9.0	28	1.5	330	0.86
FLH	22500	3,2	3	71	40	4.5	680	0.98
FLV	22500	3,2	3	73	39	4.6	680	1.01

N: number of turns; S: sensitivity [uv/nt.Hz.Hz)]; fn: natual frequency (KHz); L: self inductance (Henry); Co: capacitance (pf); ro: cupper resistance (K ohm); R: damping resistance (K ohm); d: damping coefficient.

3.3 Preamplifier

The diagram of the preamplifier is shown in fig.3-2. The amplification of the preamplifiers are selected by the receiver according to the signal & noise level. Four steps are available: x4,x16,x64,x256. Operational amplifiers OPA111 are used for the first stage of the preamplifier because they have a low noise coefficient ($8nv/\sqrt{Hz}$ at 10 KHz) and high input impedance which is important to keep the damping state stable and to prevent the natural frequency of the coil from being lowered. Low power amplifier OPA 21 is used for the second stage to reduce power consumption.

The accuracy of the amplification is higher than 1% through the four amplification steps. The bandwidth is not narrower than DC-31 KHz for the high frequency preamplifiers and DC-5 KHz for the low frequency ones.

With the input of the OPA111 grounded, the equivalent input noise is 0.80uv(RMS) for the high frequency preamplifiers with its bandwidth limited to DC-10 KHz from outside. The noise for the low frequency preamplifiers were not measured, but in theory it should be $0.8/(\sqrt{2})=0.56$uv (RMS).

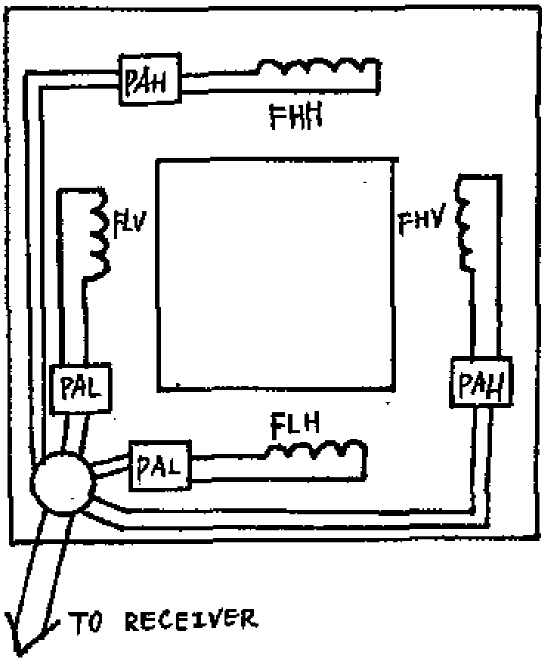

Fig.3-1 Receiver coil system. FHH (FLH): high (low) fn, horizontal coil. FHV (FLV): high (low) fn, vertical coil. PAH (PAL): high (low) frequency preamplifier.

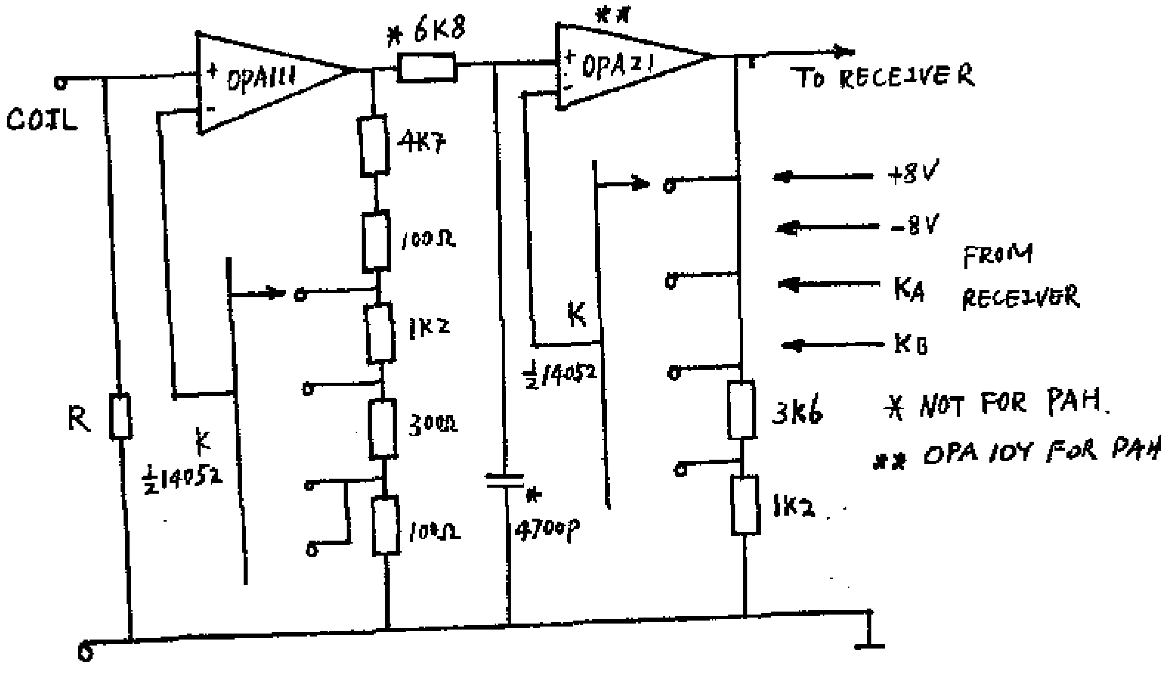

Fig.3-2 Diagram of the preamplifier.
R=680K for PAL and R=330K for PAH.

IV. RECEIVER

4.1 Introduction

The receiver is a microprocessor-controlled instrument. It has 16 channels working in time domain and 2 time-sharing channels working in frequency domain. A cmos microprocessor 1806 is used to perform the following functions: setting amplifications according to the signal level, controling and monitoring the measurement, carrying out statistic calculation during measurement, executing instructions given by the operator, handling overflows, storing the data into a bubble memory, and transfering the data to a station computer. The receiver has four inputs, each for a coil. The signals detected by the receiver coils are filtered, amplified, sampled, integrated, A/D converted, averaged and stored at each station.

For each channel, every 14 data form a group (it takes 40x14=560ms to measure). The mean value and variance of the 14 data are calculated for each group. The reciprocal of the variance is used to weight the group mean value when calculating the overall mean value over many groups of measurements in a sequent procedure during measurement.

The uncertainties on the overall mean values are also calculated and stored as a measure of the quality of the data. The demand on the uncertainties can be set via the key board by the operator before or during the measurement. And the operator can choose the uncertainties of some or all of the 16 TD channels to be checked by the microprocessor during measurement. Once the uncertainties of the chosen channels satisfy the demand, the microprocessor will stop the measurement no matter whether the desired number of measuring groups have been finished or not.

At each station, 128 bytes of data are stored in a 128k-byte bubble memory. The data contains information about

overall mean values of the 18 channels	36 bytes
amplification codes for the 18 channels	18 "
uncertainties of the 18 channels	36 "
control words of uncertainties	6 "
number of measured cycles	6 "
overflow information	6 "
date and time	5 "
coordinates	5 "
transmission parameters	5 "
others	3 "
spare ones	2 "

There is a special program in the receiver which takes care of the overflow problems, so that the relative error caused by overflows will be within +/-20% of the measured data in any case. When overflow in a channel happens more than 20% of N1, the receiver will display the channel number and beep to inform the operator. The operator has the choice of aborting or continueing the measurement. The overflow information are stored in the bubble memory for estimation of the relative error.

High stability crystal oscillators are used to keep the synchronization between the receiver and the transmitter. The drift during 8 hours is less than 10us.

4.2 Hardware discription

See fig.4-1, the block diagram of the receiver, and circuit diagrams of Card 1 and Card 2 in the Service Manuel.

A). K22 (see fig R-4 and fig R-10) After automatic scaling is finished and before the receiver actually starts measurement, K22 grounds the 4 inputs of the receiver. The instrument background noise or DC drift is measured for 256 cycles and the mean values of the background noise of the 16 TD channels are stored in RAM (2080H-209FH).
Later these noise values will be subtracted from the measured data in every cycle (40ms). After the background noise measurement, K22 connects the coil system to the receiver.

B). LP1--LP4 (see fig.R-4) 4th-order(2-nd order active +2-nd order passive)Butterworth low-press filters used to elimilate the high-frequency noises such as VLF broadcasting signal. FHV(FLV) means high (low) frequency, vertical component; FHH (FLH) means high (low)frequency, horizontal component. The bandwidth is 1.6Hz--10KHz for high frequency channels and 1.6Hz--3KHz for low frequency channels.

C). K10v, K10h K10v (see fig R-4) connects A5 to FHV when the receiver is measuring in the high frequency channel time and to FLV when measuring in the low frequency channel time (fig.2-6) K10h does the same for the horizontal component measurement.

D). A5/K11v and A6/K11h (Fig R-4) A5 (A6) is an amplifier for the vertical(horizontal) component with selectable amplification controled by software through K11v (K11h). Amplifications for low frequency channels and high frequency ones are separately selected.

E). I1/K1K2K3K4K6 and I2/K1K2K3K4K6 (Fig R-3) I1 is an active integrator with 8 identical integrating capacitors selected by switches K1- K4 and K6. The 8 capacitors are used for the 8 channels, P, S1--S7. K1 is "on"in the 8 sampling time intervals

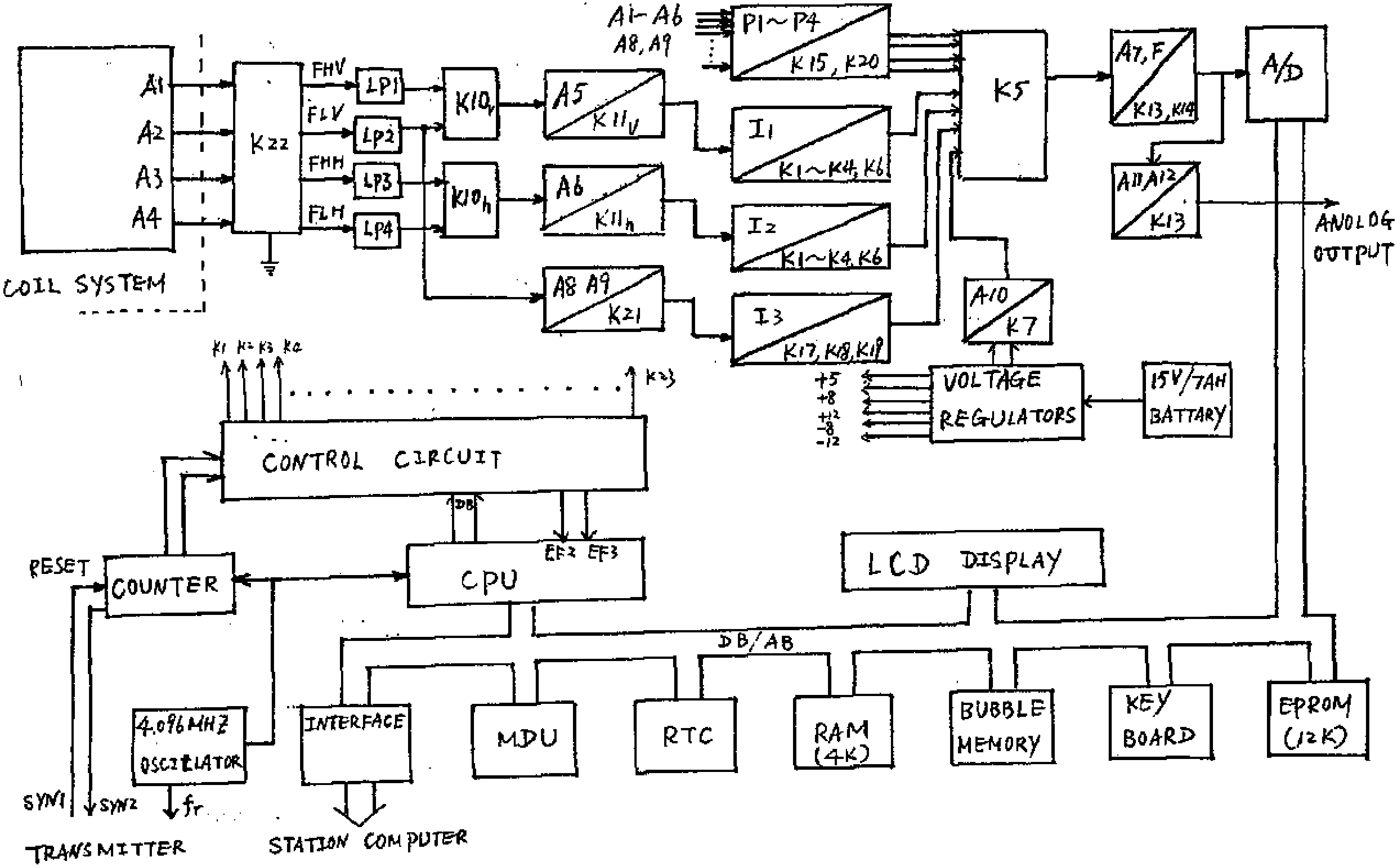

Fig. 4-1 Block diagram of the receiver.

and "off" in the other time. K2 is "off" during the sampling time and when I1 outputs the stored voltages. In the other time, K2 is "on" to keep the feed-back loop "closed". K3 and K4 are used to direct the charging current according to the polarity of the primary field which alters every 20ms, so that the primary/ secondary signals will add up in their corresponding channels. K3 and K4 are also used to short-circuit the capacitors to discharge them every 40ms after the intergrated voltages have been A/D-converted. K6 is an 8-to-1 multiplexer which selects one capacitor at a time. During the "hold" time, all switches except K2 are inhibited against being dischanged. I2/K1K2K3K4K6 are used for the horizontal component.

The time constants of I1 and I2 are identical for all the TD channels and equals to 1.25 ms. Therefore the integrators have different gains, which are propertional to the channel widths, for different channels. The gains are 1/32, 1/16, 1/8, 1/8, 1/4, 1/2, 1 and 2 for channels P, S1, S2...S7 respectively.

F). A8,A9/K21 (fig R-5) A8 is a 2nd-order LP filter. A9 is a 2nd-order bandpass filter. Both have a Q Value of 5. The total gain of A8 and A9 for the 25Hz signal is 512.The bandwidth is 2Hz. K21 is used to attenuate the 25Hz signal by a factor of 32 when the signal is too strong.

G) P1--P4/K15,K20 P1--P4 are peak value detectors (fig. R-5) used to detect and hold the maximum amplitudes of the signal and noise at each amplifiers. These maximum amplitudes are estimated to give appropriate amplification during scaling and checked to see if overflow happens during measurement. K15 is used to select inputs. K20 is used to discharge the capacitors at the end of each cycle (40ms).

H). A10/K7 (fig. R-5) At each station, the voltages of the battery and the regulated power supplies are checked before measurement. The voltages are selected by K7 and converted by the A/D convertor. The A/D output is compared with the upper and lower limits stored in the EPROM. The output of A10 is scaled so that one bit of the A/D convertor output corresponds to 10mv.

I). K5 8-to-1 multiplexer is used to select the input signal for the A/D convertor.

J).A7,F/K13,K14 (fig.R-5) A7 and F form a high-speed, low-output impedance amplifier with 4 selectable amplifications.(1,4,16,64).

K).A/D (fig.R-6) 12-bit, high speed A/D convertor AD574 was adopted. 1 bit represents 2.4414mv.

L). A11,A12/K23 (fig.R-5) A11, A12 and K23 form a sample-hold circuit which samples one of the 7 vertical-channel voltages to provide an analogue output for modelling purpose. The channel to be monitored is chosen via key board and the default channel is V4.

M). I3/K17K18K19 (fig.R-5) I3 and the related switches work in a similar way as I1 and its related switches except that a single capacitor is time-shared by two channels, V8 and V9. The integrator integrates for 120ms in every 150ms. During the 120ms, K18 is on and K19 is off, K17-1 and K17-2 reverse the charging direction every 20ms. The integrated voltage is A/D -converted during the next 20ms and then discharged for 10ms. When the second 150ms cycle starts, the phase of integrating has been delayed for 270 degrees for 25Hz signals. In every 600ms, 4 data are collected:
V8, V9, -V8 and -V9.

N). Control circuit (fig R-2,3 and 6) The control circuit consists of 5 output ports (out2,3,5,6,7) and some combination circuit to provide control signals to the switches K1--K23. The CPU sends control words to out2 and out3. When the states of the counter match the control words, Gate 18 will be opened and the output of G18 will triggle a combination circuit to yield control signals to K1--K4 and K6. The sampling sequence is controled by software, so it selectable by changing the program in the EPROM. The CPU tests EF3 to get the timing information.

A counter 4024 (fig.R-3) and a few gates were used to yield the control signals for K17, K18 and K19 for the 25Hz signal measurement. After each 150ms, a feedback signal shifts the timing sequence forwards for 10ms, so that in the next 150ms, the measured component will be 90 degrees out of phase with respect to the previous one.

Other switches are directly controled by the output ports.

O). Counter (fig.R-2) The counter consists of 3 components: 4018 (divide by 10), 4040 (divide by 2**9), and 4024 (divide by 2**5). The counter is powered on as long as the battery is connected. It is reset at the beginning of the day by a synchronization signal from the transmitter. All the measuring sequences are based on the timing pulses from the counter. The counter keeps the synchronization if only the crystal oscillators are stable enough.

P). 4.096MHz oscillator.(fig.R-7) An oven-controlled crystal oscillator OCXO is used to provide a very stable clock signal. This oscillator must be powered on at least 2 (preferably 24) hours before synchronization with the transmitter.

Q). RAM 4K on-board RAM addressed from 2000H to 2FFFH. Every 64 bytes form one page. Two pages of data are stored in the bubble memory for each observation. Memory from 2000H to 24FFH are used during the measurement. 2600 H to 2FFFH are used only for reading back the data stored in the bubble memory (maximum 40 pages each time). Data to be stored in the bubble are kept in the memory from 2000H to 207FH.
The contents of the 4K RAM can be seen from the display by keying in a proper instruction, at most 4 bytes at a time.

R). Bubble memory (figs.R-16 and 17) One mega-bit bubble memory is used to store the data for 1023 observations. As the bubble consumes very much power (several hundred mA), it is powered on only when the CPU writes data to or reads data from it.

S). RTC (fig.R-18) A real time clock 1879 is used to keep the real time during measurement. The real time information is stored in the bubble memory for each observation.

T). MDU (fig.R-15) Four multiply/divide units are used to carry out 32 bits multiply/divide calculations.

U). Interface An 8-bit parallel and a R232 serial output port is built to transfer the data to a station computer.

V). CPU 1806 microprocessor.

W). EPROM 12K-byte EPROM 6x2716 used to keep the programs.
Some trouble-shooting suggestions are given in the service manual.

4.3 Operation procedures

See also user's manuel.

A). At the beginning of a day, start transmission first. Then connect the receiver to the transmitter to adjust the frequency of the oscillators, and synchronize these two instruments.

B). Before the first measurement, key in the following information: month, date, time, profile number, number of the first station, distance between two stations, width and length of the transmitter loop, transmitter current, demand for the uncertainties, maximum number of groups of measurement at each station, etc.

C). At each station, the receiver will check the voltages of the power supplies and gives warning if any of them is out of its preset limits.

The secondary channels (1-7) can be placed in 3 groups of locations cover the whole time of the transient. The LCD will prompt "Group 1" first. Answer "1" to conform it, or any other key to skip it and then LCD will prompt "Group" 2" if still not, it will prompt "Group 3". See Table II-4 for the three groups of channel locations.

D). The receiver can execute a "scaling" program to choose appropriate amplifications for the amplifiers. The "scaling" procedure takes less than two seconds if the amplitude of the signal is no more than 1.25v(p). The scaling program can be executed at each station, or only once at the first station, or at any station at the operator's choice.

E). Each time before measurement, the 4 inputs of the receiver are grounded to measure the interior back ground noise of the receiver. This takes about 10 seconds. These back ground noises are subtracted from the later-measured data.

F). After measuring the back ground noise, the receiver execute dummy measurement for about two seconds to pass the transient process yielded by switching K22.

G). The stacking time at each station is selectable between 32 seconds and 10 hours in steps of 0.56 seconds. During the measurement the outputs of the amplifiers are monitored against overflow. The error caused by overflows is limited to within 20% of the measured value in the case by a "overflow handling"program.

H). The data storage in bubble takes about 1 sec. Then the receiver will be ready for the next observation. The data can be discarded before being stored.

I). After a whole day's work, the transmitter and the receiver should be connected together again to check the synchronization. A shift of 10us is allowed for every eight hours.

4.4 Main program (SCLKHR)

Fig.4-2 is a brief flow chart of the main program SCLKHR After reset, the receiver initialize itself and then ask "INIT ?" If the answer is 0, the previous settings, such as the storing address in the bubble, time, coordinates, etc., will be kept. Otherwise, questions like "PAGE 2?", "W=", "L=" have to be answered.

MON1 is an entrance of the program from where a new observation starts. The first thing to do is to check the power supplies. If any of them is out of its limits, its value will be displayed. Then the receiver asks "CHECK ?". Key in "1" to continue checking or "0" to branch back to MON1 again.

SCALE is a big part of the main program which estimate the signal level and sets proper amplifications for the amplifiers (see Sect.4.5). After scaling, the receiver measures its own noise and DC drift for 10 secs with the selected amplifications. The mean values of the background noise are stored in the RAM and later are subtracted from the measured data. If the background noise of any channel exceeds a fixed limit, its value will be displayed.

Two seconds of dummy measurements are carried out to pass the transient process caused by switching the inputs back to the coils. The time constant of the circuit transient is o.1 sec. After the dummy measurements, CC, N1, N3, N5 and some other bytes are set.

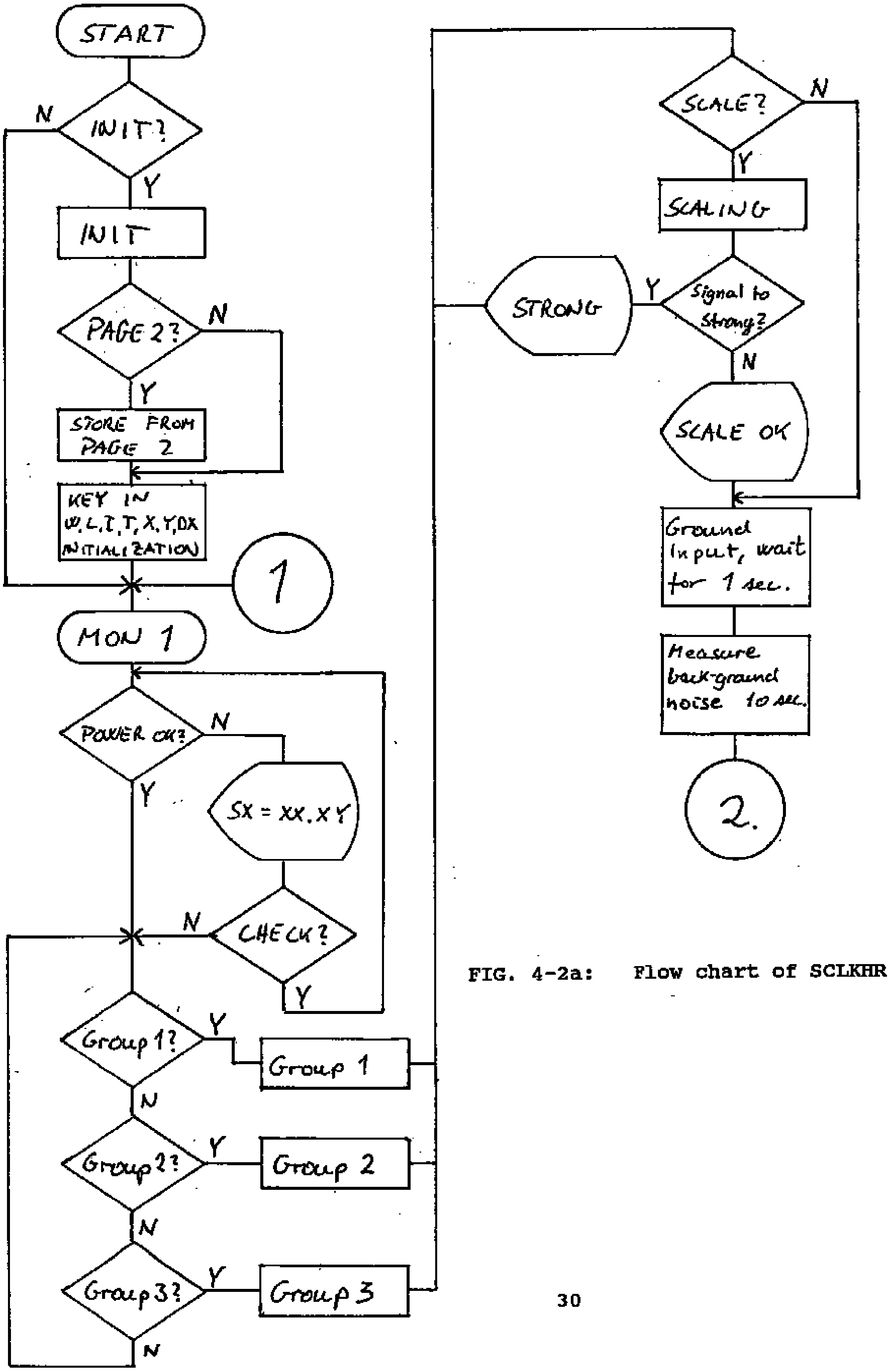

FIG. 4-2a: Flow chart of SCLKHR

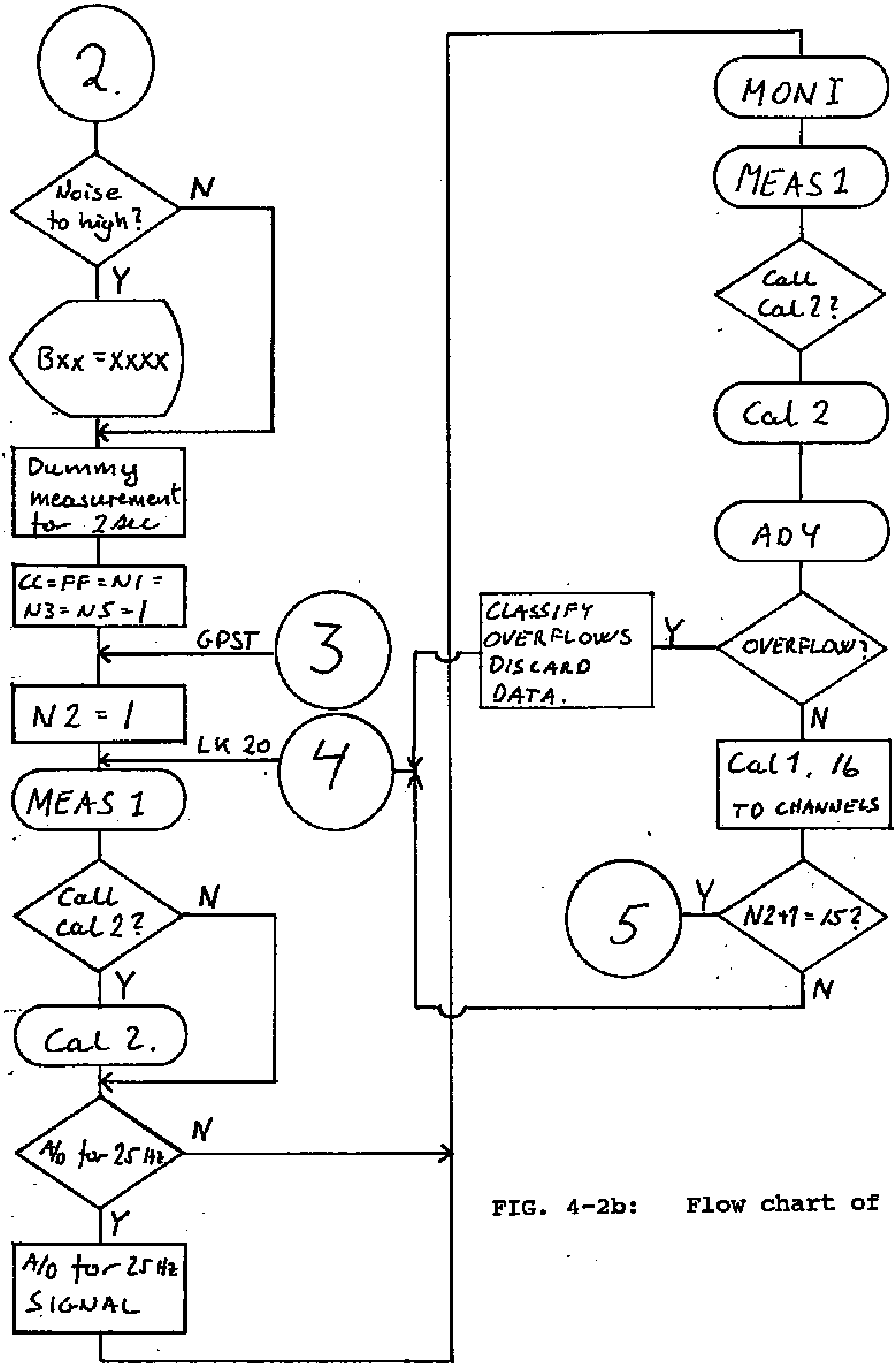

FIG. 4-2b: Flow chart of SCLKHR

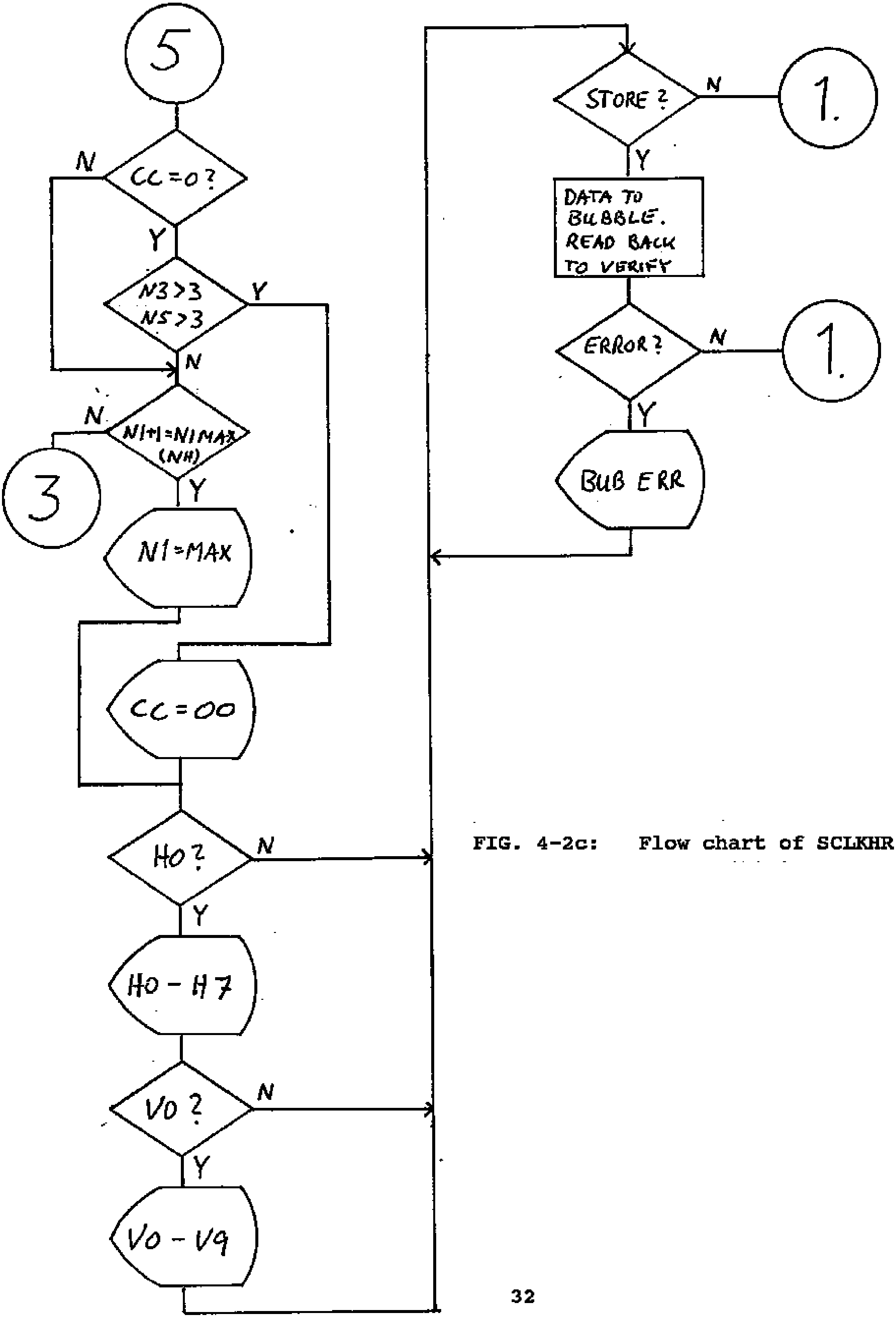

FIG. 4-2c: Flow chart of SCLKHR.

CC has 16 bits, each corresponds to one of the 16 TD channels. At the beginning, CC=FFH. When the uncertainty of a channel becomes smaller than the demand D (in 0.1%), the corresponding CC bit will be reset (0). N1, N3 and N5 are the numbers of groups of the TD channels, V8 and V9 respectively.

GPST is the start point of a new group (14x40ms).N2 is the number of the cycles in a group for the TD channels. LK20 is the start point of a new cycle. (40ms).

MEAS1 is a subroutine which generates the timing pulses for the TD channels. It also does some other things in between the sampling time intervals.

CAL2 is a subroutine which calculates the overall mean values and the relative uncertainties. CAL2 takes a maximum of 3.2ms for a single channel. It is put between the ends of S6 and S7, where altogether 3.7ms are available. In each group of measurements (0.56 sec), there are 28 such intervals between S6 and S7, and the first 18 intervals are used for calculations of the 18 channels. The calculations are such organized that during the first group of measurements, CAL2 is not executed, and during the second group CAL2 is called to calculate on the data measured during the first group, and so on. At the end of CAL2, the uncertainty of this channel of which the data has been calculated is compared with the demand D. If the uncertainty is smaller than D, the corresponding CC bit is reset. The uncertainties of V8 and V9 are not checked against D. More about CAL2 is given in Sect.4.8.

25Hz signal is converted every 150ms. EF2 is put low when either V8 of V9 is ready for A/D convertion. The CPU tests EF2 every 20ms.

MONI is an entrance of the subroutine MON(itor) during measurement.

Subroutine AD4 is called every 40ms to convert the 16 TD-channel integrated voltages, the outputs of the peak value detectors and the 25Hz signal if it is ready. Then the data are checked to see if any overflow happened during the last 40ms. If it happened, an overflow handling program will be executed and the single cycle (40ms) will be discarded (see Sects. 4.6 and 4.7).

CAL1 is a part of the main program. Each time after the A/D conversion, sums of xi and xi*xi are calculated for the TD channels. When a group is completed, the 16 sums of xi and 16 sums of xi*xi are transfered during the MEAS1 subroutine to a new address for CAL2 to work on.

When a group of 14 cycles are finished, the CPU checks the CC bits. If it is zero, and N1 is larger than 31, and both N3 and N5 are larger than 3, the stacking will be stopped. The minimum stacking time is 18.6 secs.

If N1=NH (number of groups to be finished), the stacking will also be stopped. Otherwise, a new group of cycles will be started from GPST.

If the stacking is stopped, either "N1=N1max" or "CC=00" will be displayed depending on which one has been satisfied. Then the receiver will ask "H0 ?" which is an abbreviation of the question "do you want to see the values of H0-H7 ?". If the question is affirmed (key stroke is 1), "H0=xxxxx" will be displayed. The last letter indicate unit of the measured value. It can be m"(millivolt) "U" (microvolt) or "n"(nanovolt). The displayed value is the equivalent voltage at the input of the preamplifier. Any following key stroke will advance the display to the next channel. After H7 is displayed, "V0 ?" will be asked. Answer "1" to see V0-V9 or "0" to skip them.

The next question "STORE ?" asks if the data should be stored in the bubble. If "1" is keyed in, it will ask if the X coordinate should be incremented. Answer "1" if DX should be added to X, "2" if DX should be subtracted from X, or "0" if X should remain unchanged.

Writing the data to bubble takes about 1 sec, then the data are read back for verification. In case any error is found, it will be displayed and the program from asking "STORE ?" will be executed again. So far this error has never happened.

4.5 Scaling

As mentioned earlier, the receiver has a wide dynamic range and large amplification. The signal & noise may vary millions of times on the traverse and between channels. As a big part of the main program, the scale program estimates the signal level and set proper amplification for the amplifiers stage by stage and channal by channal.

At first the amplification of the preamplifiers A1-A4 is set to the second lowest (x16). The peak value detectors P1-P4 are connected to A1-A4 for 120ms. Then the outputs of P1-P4 are A/D converted. The converted values of the high-frequency preamplifiers, A1 and A3, are compared to find the stronger one, and according to which a proper amplification is selected for A1 and A3 so that the peak value of the output of the stronger one will be within and as close as possible to 5v(p). The same is done for A2 and A4.

In the next 120ms, outputs of A5 and A6 are fed to P1 and P3 when A5 and A6 are switched to channels FHH and FHV during the high frequency channel time (from the end of S1 to the end of S3) and fed to P2 and P4 when A5 and A6 are connected to FLH and FLV during the rest time. An amplification is selected for A5 and A6 in the high frequency channel time according to the stronger one of P1 and P3, and similarly another amplification for A5 and A6 in the low frequency channel time according to the stronger one of P2 and P4.

After that, P1-P4 are connected to A8 and A9 to estimate the strength of the 25 Hz signal and to find a proper position of K21. If overflow happens at the output of A8, the selected amplification for A2 and A4 has to be lowered. In the mean time, several cycles of measurements are carried out to find proper amplifications of the last amplifier (A7 and F) for the 18 channels individually. A few more cycles of measurements are also made to check if the selected amplifications are appropriate. If overflow happened during this time, the corresponding amplification will be lowered by 1 step.

The selected amplifications are stored in the RAM in a special code form to control the amplifiers during measurement. 18 one-byte amplification codes, each for one of the 18 channels, are stored in the bubble memory for each observation. The amplifications are decoded as follows:

preamplifier	4**(b1b0+1)
intermediate amplifiers for TD channels	4**(b5b4)
intermediate amplifiers for FD channels	16*(32**b6)
last amplifier	4**(b3b2)

4.6 Overflow handling

Overflow is a tricky problem for TDEM measurement. Great effort was made to solve it in the NGUTFEM system.

If overflow occurs before scaling is finished, the related amplification will be reduced. During measurement, the CPU checks the A/D-converted data of the 18 channels and the outputs of the peak value detectors which are connected to A5 and A6. Take the TD channels as an example, if one of the TD channels overflows, the measured data for all the 16 channels in the single cycle(40ms) will be discarded and a "number of overflow group (SOVT xx)" is incremented. When the value of the maximum SOVTxx reaches 20% of N1 (number of groups), the receiver will display the channel number of the maximum SOVTxx, and beep to inform the operator.The operator can decide whether the measurement should be continued or not.
For instance, if the overflow warning occurs only a few times and then disappears as N1 grows larger, the maximum error by the overflows will be less than 20% and the measurement can be continued. But if the receiver beeps often, the best is to use the "!DN" instruction to lower the related amplification(s) and re-start measurement from measuring the background noise (see the next section).

If a SOVTxx byte is larger than 20% of N1, the other SOVTxx bytes will also be checked against a number "LIMOVT" which value is related to N1 (LIMOVT=5 when N1<64, =12 when N1<256, =51 when N1< 1280 and =255 when N1 >1280). In case SOVTxx of any channel is larger than LIMOVT, a corresponding bit will be set in one of the three bytes OVCH, OVCL or OVC56 which are marks for high frequency channels (P, S1-S3), low-f channels (S4-S7) and A5A6 respectively. When "!DN" is issued, these three bytes will be examined, and amplifications of those channels whose corresponding bits have been set to "1" will also be lowered.

SOVGH (SOVGL) keeps the number of overflows of A5 and A6 in a group when A5 and A6 are connected to FHV (FLV) and FHH (FLH) respectively. If overflow happens there, the measured data of the 16 TD channels in that cycle will also be discarded. SOVTH (SOVTL) keeps number of overflowed groups of A5 and A6 during the measuring times of P-S3 (S4-S7).

If overflow happens in V8 (V9), the measured data will be discarded, and the related bytes SOVTV8 (SOVTV9) will be incremented, but the measurement in the TD channels will not be affected.

Eighty bytes of overflow information are kept in RAM from 2400H to 244FH, and 6 bytes of them are to be stored in the bubble memory for each observation.

4.7 Lowering amplifications

When the number of overflowed group is larger than 20% of N1, the operator can key in an instruction "!DN" to lower the related amplification(s) and re-start the measurement. First, CPU will look at OVC56. If OVC56 is not zero, the amplification of A5A6 for the corresponding channels will be lowered by 1 step. For instance, if A5A6 overflows when they are connected to the high frequency channels, the amplifications of A5A6 will be lowered during P-S3 time, and once this is done, OVCH does not need to be checked any more because the total amplifications of all the high frequency channels have been lowered. If OVC56 is zero, OVCH and OVCL will be examined. If only 1 bit in OVCH or OVCL is "1", the amplification of the last amplifier (A7 and F) for that single channel will be lowered by one step. In case more than one bit in OVCH (or OVCL) are "1", the amplifications of A5A6 for high (or low) frequency channels will be reduced.

When an amplification needs to be lowered but it is already in the lowest step, the amplification of the previous amplifier will be lowered. In case the amplification can not be lowered any more, the display will show "STRONG !" and wait for instruction from the key board.

"Lower" is part of the main program, but it is branched to from inside the subroutine "MON". The return address, stack pointer, etc. have been properly taken care of.

4.8 Statistic calculation (subroutine CAL2)

Statistic calculation is carried out to estimate the quality of the measured data and to optimise the data in real-time.
For each channel, every 14 measurements form a small group. A "goodness factor" Kj is defined for the J-th group:

$$Kj=n*n*A/[\sum_{i}^{n}(xi*xi)-n*aj*aj],$$

where $aj=(1/n)\sum_{i}^{n}xi$. aj is the mean value of the j-th group, xi stands for a single number in the j-th group, n=14, A=2**18. xi is in the range (-2**11, 2**11). The denominator of Kj can be as large as 14*(2**22). A is used to make Kj big enough so as to avoid the trouble of handling floating numbers, which is difficult for the 8-bit microprocessor in real-time.

The weighted overall mean value is defined as

$$M=\sum_{j}^{G}(Kj*aj)/\sum_{j}^{G}Kj \qquad (4-1)$$

where G is the number of groups. M is a better estimate of the expectation of x than the arithmetic mean value

$$M'=(1/G)*\sum_{j}^{G}aj.$$

During a field working day, the noise level may vary quite much. In quiet periods, less stacking time is needed to obtain the data in good quality. The NGUTFEM system constantly checks the qualities of the measured data and once the uncertainties of the mean values are smaller than the demand, stacking will be stopped automatically. The relative uncertainty of M is defined as

$$u=(1/M)*\sqrt{A}/\sqrt{\sum_{j}^{G}Kj}\ .$$

We can demand the uncertainty (in 0.1%) to be less than a small number D, i.e., u*1000<D. D can be any integer between 0 and 9999.

Subroutine CAL2 performs the statistic calculation. The flow chart of CAL2 is shown in fig.4-3, where MI stands for aj, $\sum$XI for $\sum$xi, KI for kj, $\sum$(XI)**2 for $\sum$(xi*xi), and U for u*1000.

At first MI, KI and $\sum$Ki are calculated. Then $\sum$KI is checked and if it is very big already (>FCXXXXXXH), the following calculation will be skipped. If not, M will be found according to (4-1). When M is zero, it is replaced by 1.

The corresponding CC bit is reset to zero if the uncertainty becomes smaller than the criterion D or if $\sum$KI has been very big, which also means high quality of the measurement. There is no CC bit for V8 and V9 because they are most often with good quality.

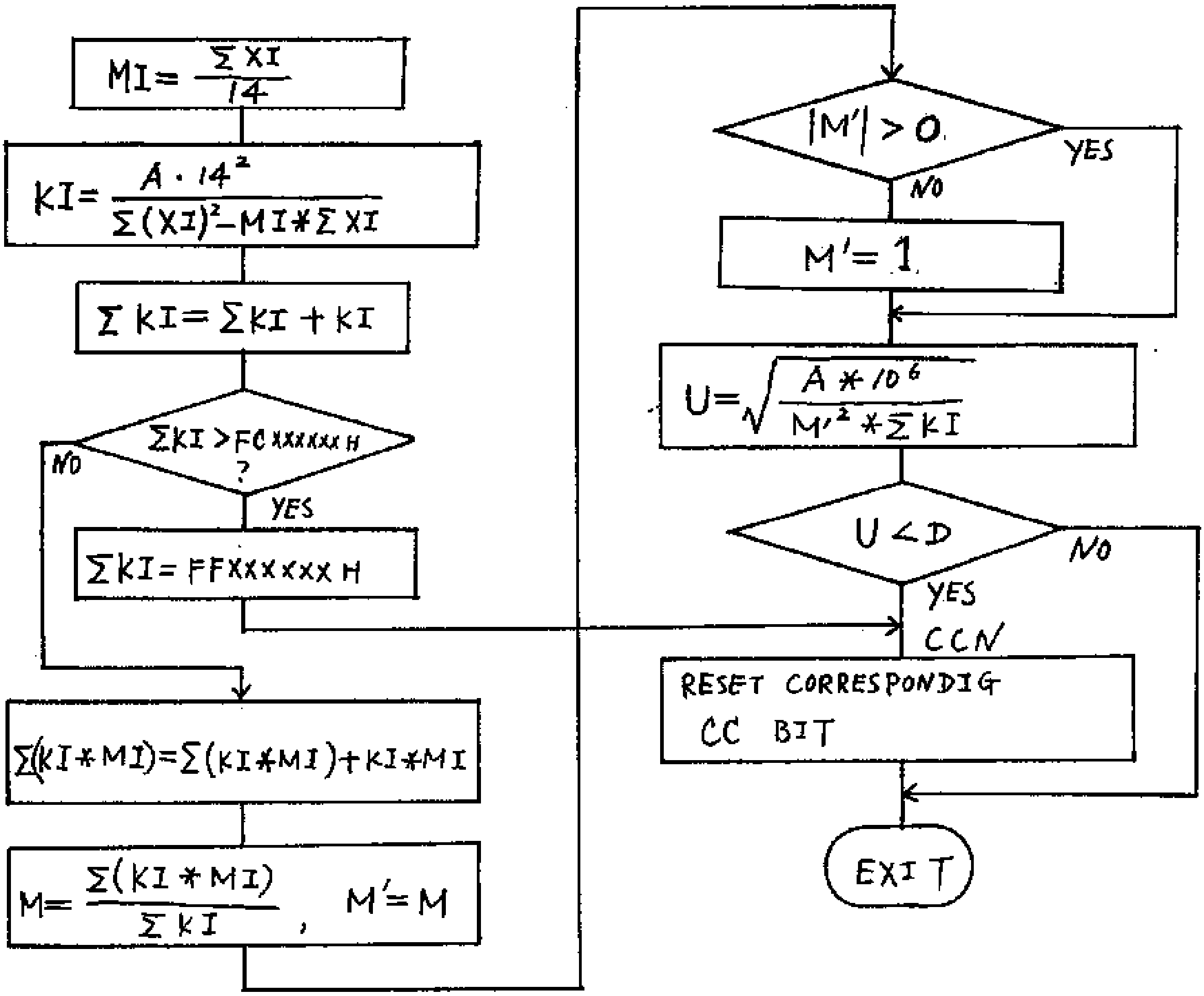

Fig. 4-3 Flow chart of subroutine CAL2.

4.9 Monitor (subroutine MON)

MON is a subroutine developed to execute the instructions given via the keyboard. It has two entrances, MON and MONI (fig.4-4). When MON is called, the CPU will wait for a key stroke. If the key stroke is "RET", it means an instruction has been keyed in and the CPU starts to interpret and execute the instruction. If it is not "RET", the key stroke will be identified, stored and displayed.

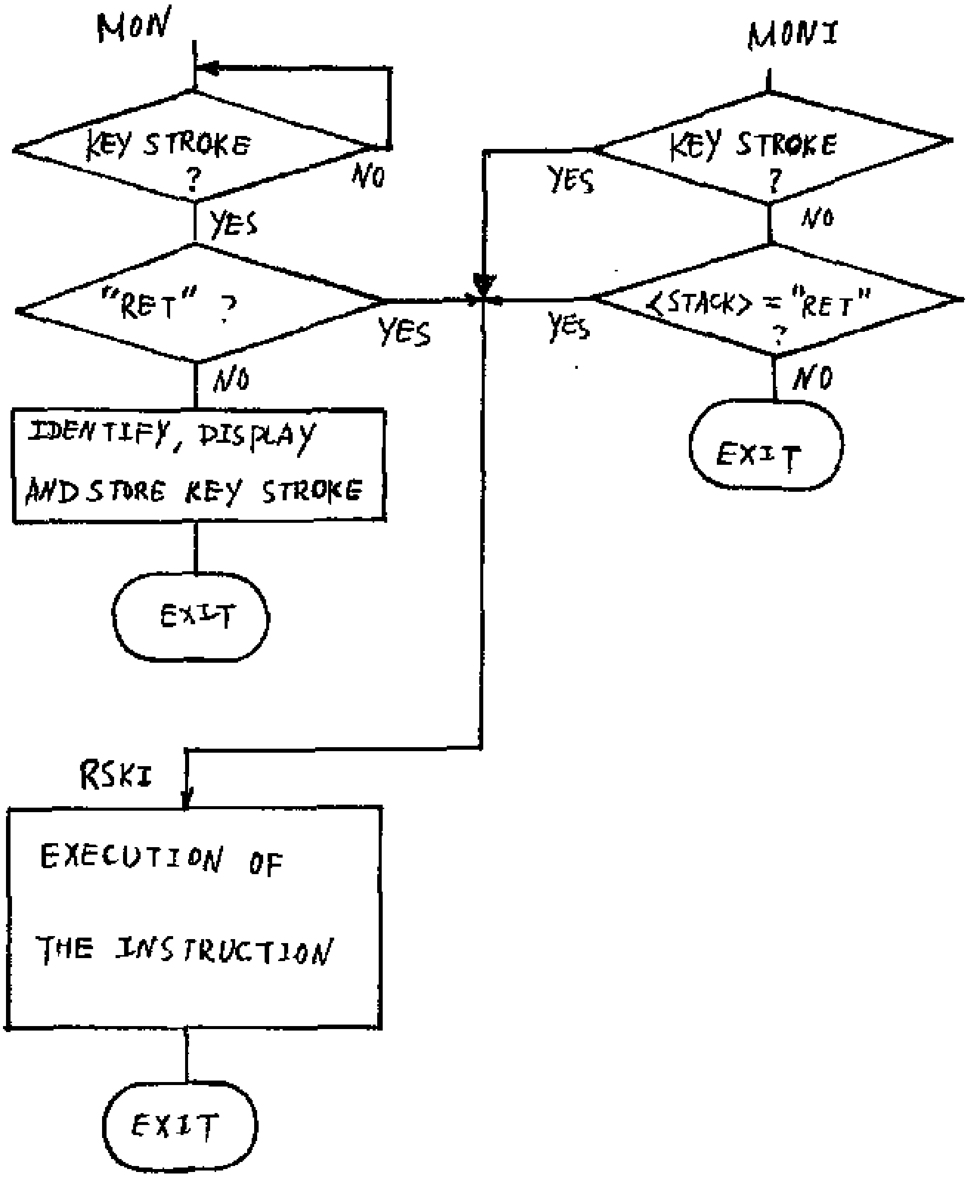

Fig. 4-4: Flow chart of MON (monitor).

MONI is an entrance for MON during stacking time. "STACK" is the top of the key stroke stack (KBS). If "RET" is stored in STACK, the instruction stored below STACK will be executed every 40ms during stacking time. This was designed for instantaneous display of many quantities which vary during stacking, such as time, N1, N3, N5, mean values of the 18 channels, uncertainties, CC bytes, overflow state, etc.

The default instruction stored in KBS is "?V0 RET". Once the stacking start, voltage of V0 will be displayed. If "RET" is struck once after the stacking has begun, the instantaneous value of V0 will be displayed.

In case an erroneous instruction is given or a instruction can not be executed correctly, "ERR" (error) will be on the display.

4.10 Explanation of instruction list

This is an explanation to those instructions of which the brief explanation given in the instruction list in the users manual might not be sufficient.

?: to read from RAM
!: to write to RAM
#bytes: number of bytes
the number next to "#bytes": address of the lowest byte in RAM
C1,C2 and Cd: coordinates x, y and increment of x
CH,CV: control bytes of uncertainties (CC). Before stacking, they are copied from CHS and CVS.
CHS,CVS: masks of CH and CV. If quality of some of the channels is not important the operator can reset their corresponding CHS or CVS bits via keyboard.
D: demand on uncertainties (0.1%). Default value: 50(5%)
DH0-DH7,DV0-DV9: uncertainties of channels H0-H7 and V0-V9.
H0-H7,V0-V9: overall mean values of channels H0-H7 and V0-V9.
NH: number of groups of cycles of the TD channels to be finished. Default value: 100.
NS: number of pages stored in bubble.
N1,N3,N5: numbers of finished groups of the TD channels,V8 and V9
SH0-SH7,SV0-SV9: amplification codes for H0-H7, V0-V9.
SHH,SNH: amplification codes of A5 and A6 in high (low) frequency channel time.
S13,S24,S25: amplification codes of A1A3, A2A4 and state of K21.
S0-S7: power supply values in volts. The standard values are -8v, -12v, -15v, 5v, 8v, 0v, 12v, 15v.
VC: channel number of the analogue output from connector C2 for modelling or testing purpose.
1(2,3,4)Hxxx: display 1(2,3,4) byte(s) in HEX starting from the address 2xxxH (and down).
1(2)Dxxx: display 1(2) byte(s) in Decimal starting from address 2xxxH (and down).
ST1,ST2: starting and ending page numbers when transferring data from the receiver to station computer.
STH: start data transferring from receiver to computer.

4.11 Memory map

There are 4 K-byte RAM on the CPU card in the receiver addressed from 2000H to 2FFFH (see the memory map in Service manual) The first 128 bytes are memories for temporary storage of the data to be stored in the bubble memory. MH0-MV9 are two-byte mean values of the 18 channels. SCH0-SCV9 are one-byte amplification codes. UH0-UV9 are two-byte uncertainties (in 0.1%). S (D) is the demand on the uncertainties. See the instruction list for CHS--N5. SOVTmax-- OVCh are overflow information. MONTH--SEC are real time. Y,X and ▲X are coordinates. I, W and L are transmitter current(in 0.1 A) and width and length of the transmitter loop in Meter.(207CH keeps the Group number (I for Group 1, etc).207BH and 207DH are spare bytes. PN1 is the page number which indicates the address to where the 128 bytes are going to be stored. In the bubble one page equals to 64 bytes. Each time two pages is writen into the bubble. Pages 0 and 1 in the bubble are reserved to keep the latest PN1 only. Each time before writing to the bubble, Pages 0 and 1 are read back to get PN1.

Memories 2080H-209FH keep the background noise for the TD channels. BG limit is the limit of the background noise. READvo and READrho are answers to questions "V0 ?" and "H0 ?".

Memories 20B0H-20D3H keep the measured values of the 18 channels. *TEMP3 and X2 are for temporary* data storage. N1max keeps NH. See Sect.4.10 for VC, ST1 and ST2. N2, N4, N6 are numbers of cycles of the TD channels, V8 and V9 in a group.

Memories 2100H-21DFH, 21F2H-21FFH and 2200H-22FFH are used to keep the intermediate results of calculation. 21E0H-21F1H are used *to indicate the channels for which CAL2 has been executed.*

2330H-233FH are keyboard stack. 2350H, 2351H and 2360H-2386H are amplification control bytes. 2352H-2356H are some flags for measurement. 2358H-23BFH keep data from the 4 peak value detectors. 23C0H-23CFH keep power supply values in 0.1 volt.

2400H-244FH are overflow information (see Sect.4.6). 2450H-247FH are used to keep return addresses when calling subroutines. 2480H-24FFH are memories to where the data read back from the bubble, for verification or transfering to station computer are first stored.

Memories from 2600H to 2FFFH (40 pages) are used as data stack during data transferring from the bubble to station computer. Memories from 2500H-25FFh are not used.

V. TRANSMITTER

5.1 Introduction

The first model transmitter was a combination of a power supply and a transmitter. The conducting angle of the rectifier bridge was dynamically adjusted according to the voltage drop across the regulating power transistor so that this drop is between 15v and 30v. Trouble arose from the fact that both the frequency of the AC power supply and the repeaded frequency of the transmission are 50 Hz. As they were not synchronized, the gradually changing phase difference caused large fluctuations in the rectified output voltage which consequently resulted in damage of the power transistors.

The second model transmitter does not include a power supply part. A separate power supply was built to convert the AC power into a DC power. The new transmitter was built to perform the following functions:

A). To send current pulses of up to 12.6 A (peak value) with alternative polarity into a transmitter loop or a grounded transmitter cable. The trailing edge of the current pulses should be cleanly terminated and should have a width in the range (100us,2.5ms).

B). To keep synchronization between the transmitter and the receiver by oven-stabilized crystal oscillators so that no line connection is needed during measurement. The drift of the synchronization must be less than 10us in 8 hours.

C). To monitor and display transmitter parameters instantaneously during transmission.In case something is seriously wrong, transmission must be stopped at once to avert any accident or damage, for example if I>12.6a or loop is broken.

5.2 Hardware description

Figure 5-1 is a block diagram of the transmitter. See Service Manual for the details.

A). Transmitting network See fig. T-2. The main network is formed by 4 thyristors SC1-SC4 and a power transistor T3. When SC1 and SC4 are triggered and T3 is switched on, the transmitter current flows through SC1, the loop, SC4, and T3 for 10ms. Then T3 is switched off, the transmitter current continues to flow through SC4, D8, D7, T1, D5 and the loop and decreases almost linearly to zero in several tens or hundreds of microseconds. Ten milliseconds later, SC2 and SC3 are triggered and T3 is switched on, and a similar cycle is started except that the direction of the transmitter current in the loop is reversed. OPTO1 is used to get information of the width of the trailing edge and to generate synchronization pulses. The transmitter current value is found by measuring the voltage drop over R078.

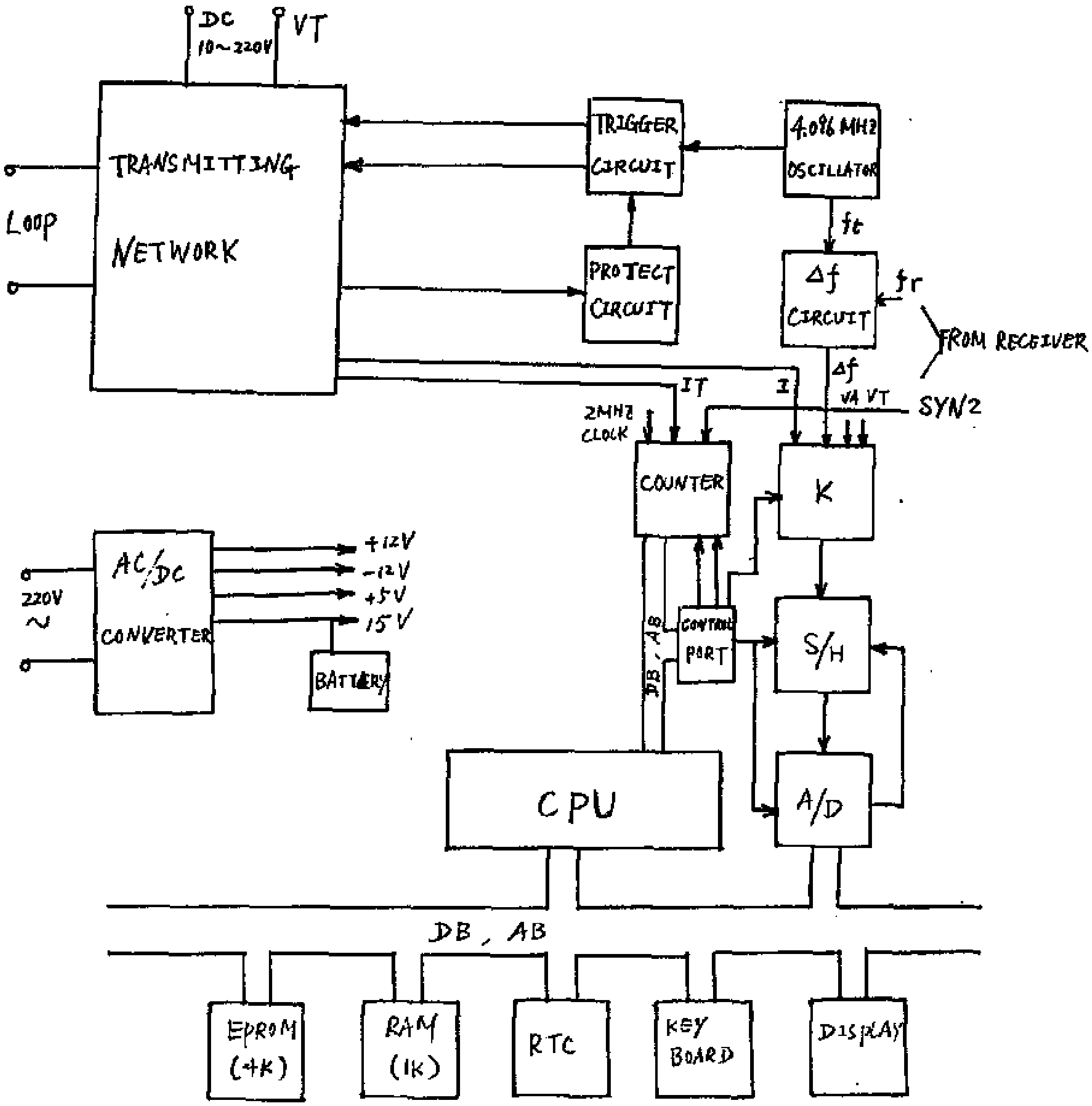

Fig.5-1 Block diagram of the transmitter.

B).Trigger circuit See fig.T-3. Counters and combination circuits are used to generate triggering signals for SC1-SC4 in two alternating groups and the control signal for T3 (via T2).

C). Protection circuit (fig.T-3). When the transmitter current is higher than 13A, C1 is triggered and it will hold T3 (via B2 and T2) off for a few seconds.
* Transmitter current is limited to 12.6A by a software high current protection.

D).Δf circuit (fig.T-4). This circuit mixes fr and ft, and outputs their diffrence to S/H circuit. The output waveform is like full-wave-rectified half sine wave pulses with a peak value of 1v.

E). K 8-to-1 multiplexer AC7501.(fig.T-4) Only 4 inputs are used. Input I, VA, VT and Δf are measures of the transmitter current, the AC voltage, the DC transmitting voltage and the difference frequency between fr and ft.

F). A/D 10-bits A/D convertor AD571(fig.T-4) Only the eight highest output bits are used.

G). Control port An output port (A2,fig.T-4) which sends control signal to K, S/H, A/D and the counter.

H). Counter (B3 and B4,fig.T-4) It is used to count the 2MHz clock pulses gated either by IT to measure the width of the trailing edge, or jointly by IT and SYN2 to measure the synchronization drift (in us).

I). AC/DC power converters and battery (fig.T-5) 220v AC input is converted by the converters into +/-12v and +5v as the operating power supplies and +16.5v to charge a 4AH,14.4v rechargeable battery pack which is used to keep the crystal oscillator running during transportation and over night, a fully changed battery pack can last 24 hours.

J). CPU, 4.096MHz oscillator, key board, display, RTC, RAM and EPROM Identical to those in the receiver (see Chapter IV).

5.3 Main program

Figure 5-2 is a flow chart of the main program of the transmitter.

When the transmitter is turned on, the operator can go into MON (itor) program to check transmitter parameters such as VA and VT, or to measure the frequency difference and to adjust the oscillators (see users Manual).
The operator can initialize the transitter and set the real time by answering"1"to the prompted question, or skip them by answering"0".

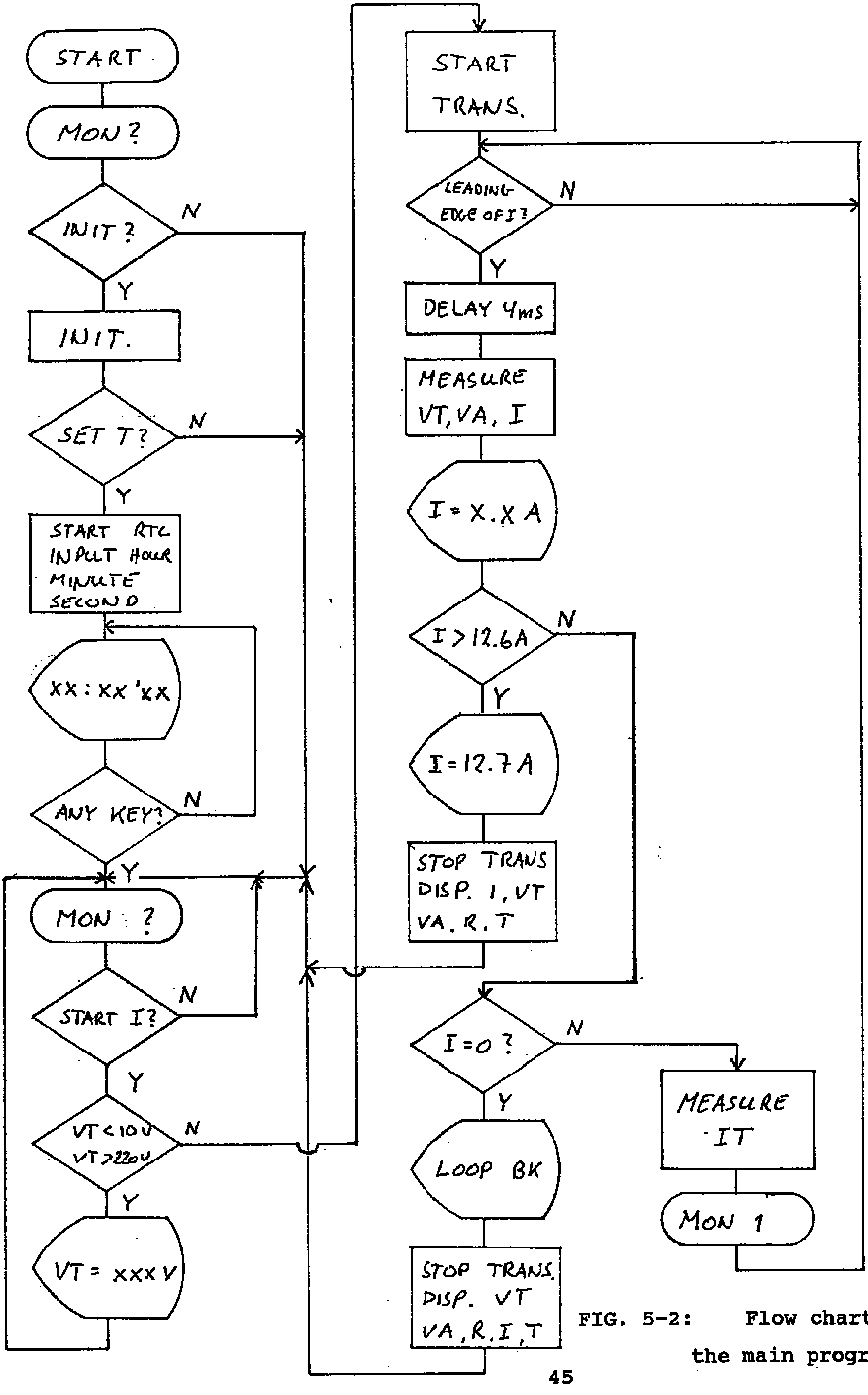

FIG. 5-2: Flow chart of the main program.

After that, a question "START I?" is displayed If "1" is keyed in, transmission will be started if VT is within the range 10-220v.The CPU measures VA, VT and I during the transmitter on-time and displays the current value in amperes. The width of the trailing edge IT is measured in the turn-off time.

The value of I is checked in each cycle. If I >12.6A (loop short circuited) or if I <0.1A (loop broken) the transmission is stop at once to protect the transmitter or any lifestock which is breaking the loop.

If there is any key stroke during transmission, MON will be called at MONI.

5.4 Monitor (subroutine MON)

MON is a subroutine similar to that of the receiver except that this MON is much shorter. The following instructions from keyboard can be recognized and executed by the MON.

VA: display AC voltage in volt.

VT: display transmitting voltage in volt.

I: display transmitter current in Ampere.

IT: display width of the trailing edge in microsecond.

R: calculate the loop resistance by R=(VT-6)/I, where 6 is the voltage drops across the switching components, then display R. Only after transmission has been started can this calculation be correct.

FT: check synchronization and display the drift in microsecond. The transmitter and the receiver must be connected.

FF: calls subroutine OSAD to measure the time needed for Δf to vary for one degree. The time is displayed in a special form such that when the displayed number is bigger then 1500, the synchronization drift will be less than 10us during a working day (8 hours).

T: display the real time.

Many more instructions related to the error control program can be recognized by the MON, but their service programs are not made becase field experience shows that they are not necessary. Malfunction may occur if these instructions are keyed in. Such instructions include:

LVA (LVT, LI, LIT)--list VA (VT, I. IT) values stored in the memory during a day.

VAH, VAL (VTH, VTL, IH, IL, ITH, ITL)--the maximum and minimum VA (VT, I, IT) during a day.

ER-- list errors occured during a day.

In case malfunction occurs, push the reset button and restart transmission.

VI. POWER SUPPLY UNIT

The power supply unit is a switch mode power supply which converts the 220v AC power into a DC power with an output voltage contineously adjustable from 32v to 212v and an output current capacity of up to 12.6A (pulsed, 10ms duration and 50% duty cycle).

Figure 6-1 is the block diagram of the power supply unit. The circuit diagram is given in service manual, fig.P-2.When it is first turned on, C1 is charged to about 310v, Uout=0v. Voltage drop on transistor T2 is zero. Control circuit CT will switch on the power transistor T1 to charge C2. The charging current increases almost linearly in a few hundreds of microseconds to about 15A. Then the current sensor IS1 will trigger CT to switch off T1 for about 200us. This is to protect T1 from over current. When T1 is off, the magnetic field energy (L*I*I/2) stored in L has to be released, so the current continues to flow through L and C2 via power diode D and gradually decreases. This charging procedure repeats until Uout reaches the manually selected value (MS) and the voltage drop VT2 is higher than 6v. Then VS1 will trigger CT to switch off T1 and hold it off until VT2 drops to below 4v.

RT is a temperature-sensitive resistor attached to the heat sink of the power transistors. If the temperature is higher than about 70 deg.c., T1 will be switched off to prevent it from being damaged. IS2 and VS2 are respectively used to protect T2 from high current and high voltage drop which may happen when the load is too heavy or when the output is short circuited.

Optocouplers are used to isolate CT, VS1 and VS3 (fig.P-2) so that their operations are not affected by the high voltage differences between them. CT and VS1 are working in a floating state. When testing any thing there , be sure that the testing instrument has no direct connection to the ground or the real common of the power supply unit.

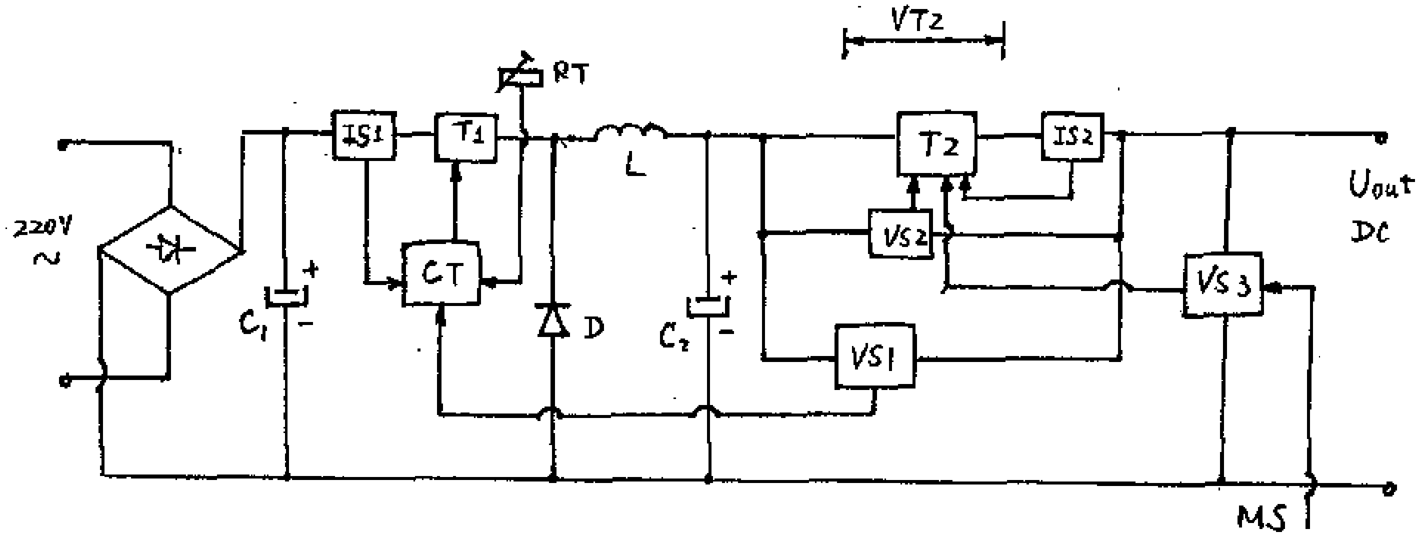

Fig. 6-1 Block diagram of the power supply unit

VII FIELD TESTS

During 1985 the NGU -TFEM system was tested seven times at Tempervoll and twice at Kongsvoll, Oppdal. Some result from this was presented at the 16.NOFTIG meeting in Trondheim in january 1987 (Elvebakk et al 1987). In 1986 the system was tested with good results in three different mineing areas in Norway (Rønning 1987 a,b and c). After some improvements, the instrument was tested again in Joma and at Kongsvoll in 1987 (Rønning 1988, Elvebakk & Rønning 1988). After this last testing period, the system sems to work quite well.

VIII. IMPROVEMENTS AND CHANGES MADE IN 1987.

8.1 Receiver

1. Software mistake which results in small measured values in H2 - H7 and V0 - V7 is removed.
2. Display errors in reading small values are corrected.
3. RS232 interfase is made available.
4. A switch is used to enable the RESET signal from the transmitter during synchronization and to disable it in other time, so that synchronization will not be lost when the receiver and the transmitter are connected again
5. Adjust of FF is made finer.
6. Inner connection is rearranged and structure is reinforced to make the receiver more rugged.
7. Sofware changes are made through out the program to facilitate field operation.
8. Data quality control program modifield to give more reliable estimate of quality.

8.2 Transmitter

1. High current and open loop protection are incorporated.
2. Heat insulation for the Oscillator is improved to keep it stable.
3. The program is rewritten , and hardware changes is made to facilitate adjustment of FF.
4. Transmitting network is rebuilt for higher reliability and more accuerate measurement of IT.

8.3 Power supply

1. Some circuit are changed to improve the capacity of carrying heavy load.
2. Possitive temperature coefficient of the output voltage is realized to compensate the reduction of transmitter current due to high temperature.
3. An old card is replaced by a new card to ensure safety.

IX REFERENCES

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