CHOPPING WAVE METHOD FOR REMOVING ELECTROMAGNETIC INDUCTION COUPLING[①]

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ABSTRACT A chopping wave decoupling method was proposed, by which the electromagnetic induction coupling(EM) effect could be directly removed. This method was based on the appearance characteristics of the induced polarization(IP) effect and the EM effect in the measured wave form. The applying conditions and the applying effects of this method were also discussed. Very good decoupling effect in the field had been obtained using the instrument designed on this method.

Key words: induced polarization effect electromagnetic induction coupling chopping wave method decoupling method

1 INTRODUCTION

To suppress and remove the EM effect has been become an important research project in frequency domain IP method since the "variable frequency method" was advanced by Wait, J. R. The reasons are: (1) The EM effect is a strong disturbance of the IP anomaly, it hinders the application and affects the investigation depth of the IP method, especially in the areas covered by a low resistivity stratum, or in other research such as looking for oil deposits, gas fields, coal fields, and underground water using weak IP anomaly. (2) More and more attentions have been paid to the evaluation of the IP anomaly. When applying the IP spectrum or the IP nonlinear effect to evaluate the IP anomaly(e. g. to distinguish metallic sulfide and carboniferous strata, or to distinguish massive and immersion sulfide ore), it is difficult to perform measurement because of the EM effect.

Since 1950's, the basic theories and laws of the EM effect have been studied by overseas under all kinds of typical circumstances(e. g. homogeneous earth, stratified media). Since 1970's, the research of the decoupling method has been become more popular. The representive methods used by Zonge, K. L. and other scholars were (1) to correct the IP and EM effects respectively with multiple frequency measurement supposing the IP and EM effects meet different laws with the variance of frequency; (2) to subtract the theorectical EM effect from the measured field data and than using the remainders as the EM effect. Pelton approximately considered the EM effect as a cole-cole model of $C = 1$, and subtracted it from the field data. A lot of research in domestic have been done by Luo yanzhong, Wang Jilun, Liu song, *et al.* and some achievements have been made. All of these works suggest that both the IP and EM effects are of a simple algebra addition in total effect.

Although certain achievements have been obtained in oversea and domestic, there are three common questions remained. (1) All of these methods are indirect to subtract the ideal EM effect from the field data. (2) All of the correcting methods are conditional and approximate, and the approximate degree is not very high, especially when the EM effect is relatively strong to cover the weak IP effect. (3) In order to correct the EM effect, not only the indoor calculation but also the amount of the field work are necessarily increased.

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Based on the characteristics and the laws of the IP and EM effects those are systematically researched, the chopping wave decoupling method is advanced in this paper, by which the EM effect can be directly removed in field surveying. In addition, the applying effect and the applying condition are discussed. The "Anti-coupling dual-frequency digital IP instrument" developed on this theory has been widely used in China and very good geological effect has been obtained. This scheme has also been used in the designing of C−2 micro-sounding instrument. Many applications show that this method is feasible and can obtain very good effects under most geological conditions.

2 GENERAL LAWS OF THE IP AND EM EFFECTS

There are mainly three supplying current waves used in the IP surveying. One is the single-frequency square wave used in the variable frequency method. The second is the dual-frequency square wave proposed by the authors. The third is the step current wave generally used in the time domain IP method.

In order to calculate the measured voltage wave form in frequency domain, the supplying current wave form needs to be expanded in Fourier series.

To the dual-frequency wave, its Fourier series is

$$\begin{cases} F(t) = \sum_{n=1} A_n \cdot \sin(n\omega_0 t) & (1) \\ A_n = \begin{cases} 0 & n \text{ is even} \\ \dfrac{2}{n\pi} \sum_{J=1}^{n} \left[\cos\left((J+1)n\dfrac{\pi}{13}\right) - \cos\left(Jn\dfrac{\pi}{13}\right)\right] & n \text{ and } J \text{ are odd} \end{cases} & (2) \end{cases}$$

To the single-frequency square wave, its Fourier series is:

$$\begin{cases} F(t) = \sum_{n=1} A_n \cdot \sin(n\omega_0 t) & (3) \\ A_n = \begin{cases} 0 & n \text{ is even} \\ \dfrac{4}{n\pi} & n \text{ is odd} \end{cases} & (4) \end{cases}$$

To the time domain supplying wave form, it can be expanded as the following:

$$\begin{cases} F(t) = \sum_{n=1} A_n \cdot \sin(n\omega_0 t) & (5) \\ A_n = \begin{cases} 0 & n \text{ is even} \\ \dfrac{2}{\pi} & n = 1 \\ \dfrac{n-2}{n} i^{n-1} \cdot A_{n-2} & n \text{ is } 3, 5, 7, \cdots \end{cases} & (6) \end{cases}$$

where $\omega_0 = 2\pi/T$; T is the period of the wave; i is imaginary unit, $i = \sqrt{-1}$

After frequency response of the EM effect and the IP effect were obtained, the appearance forms of the EM and IP effects in each measured waveform can be obtained. This kind of calculating method is called the "wave form recovery". The recovered results of the three supplying current waves are shown in Figs. 1~3. We can sum up some laws as following.

(1) The EM effect has similiar appearance in all kinds of the measured wave forms.

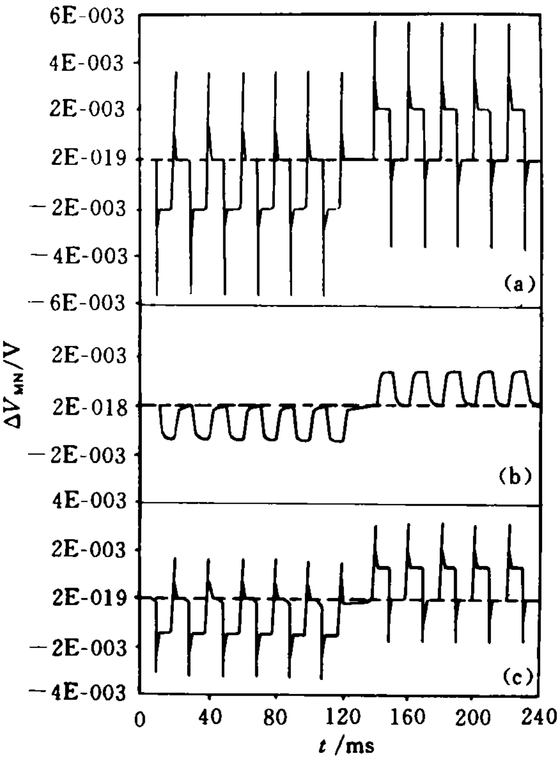

Fig. 1 The measured voltage waveforms containing EM and IP effects in dual frequency IP method

(a)—for EM effect only; (b)—for IP effect only; (c)—not only for EM but also for IP effects

According to the electromagnetic induction theory, the EM effect mainly appears at the rising and descending edges of the waveform. In the figures, a strong sharp pulse appears at the edge of rising and descending of wave form symmetrically. Its amplitude is approximately 2.5 times of the normal waveform. The width of the sharp pulse is very small, about 1/20 times of the wave period.

(2) In the three measured waveforms, the appearence of the IP effect is similiar to the charge and discharge curves of a RC network. At the rising edge of the waveform, ΔV_{MN} jumps to a certain value, then charges in different speeds. When the charge time is long enough, ΔV_{MN} can get a limit value. On the contrary, at the descending edge of the wave form, the IP effect is a discharging process. ΔV_{MN} jumps to a certain value, then attenuates to the normal value (when the discharge time is longe enough).

(3) When both EM and IP effects being existed, the measured wave form is the superposition of the two effects. Obviously, this superposition is not a simple algebraic addition, but a superposition after a complex interaction. In Fig. 2, and Fig. 3, because the frequency is not very high and the IP effect is relatively strong, the IP and EM effects display their own characteristic in the measured wave forms. To the dual-frequency wave in Fig. 1, the IP effect, especially its high frequency composition, seems to be covered by the EM effect. The reason is that the higher the frequency is, the stronger the EM effect would be. On the other hand, the higher the frequency, the weaker the IP effect. Even so, the IP effect can still be found in the low frequency envelope. By using the special appearance forms of the EM and IP effects in dual-frequency wave we can also extract the IP effect and the EM effect in surveying respectively.

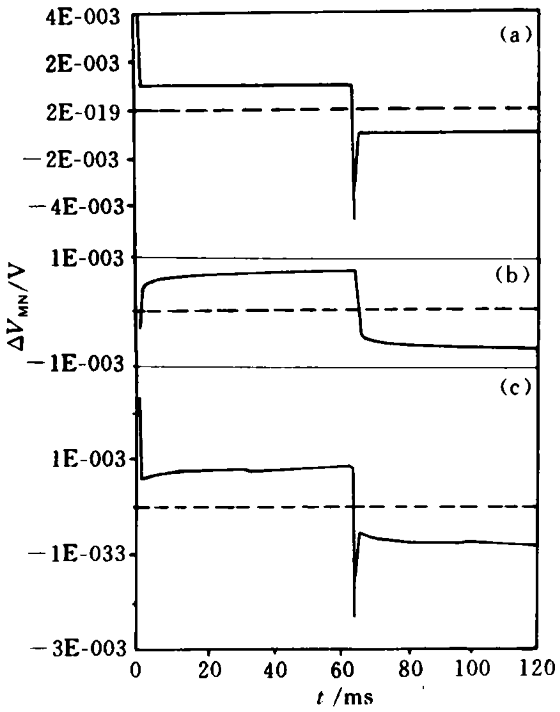

Fig. 2 The measured voltage waveforms containing EM and IP effects in variable frequency IP method
(a), (b), (c)—the same to Fig. 1

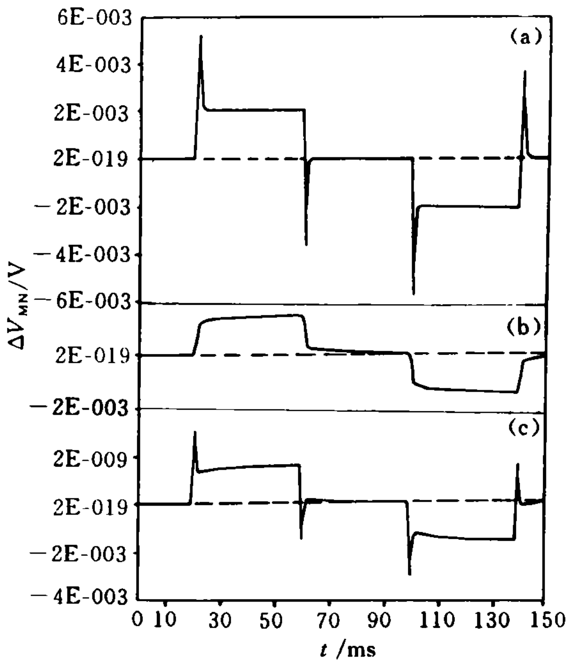

Fig. 3 The measured voltage waveforms containing EM and IP effects in the time domain IP method
(a), (b), (c)—the same to Fig. 1

3 THE ATTENUATION LAWS OF THE EM AND IP EFFECTS

Generally, we suppose that the IP and EM effects meet the exponential attenuation laws and fit the algebraic superposition relations. Here we will inspect this assumption.

Using the wave form recovery technology, and letting sample interval equals 6.28 ms, 1 000 discrete points can be obtained for the dual-frequency wave with period of 2 π. Then the rising or descending edge of the wave form is considered as the starting point, the attenuation curves of the EM and IP effects are fitted according to $\Delta V_{MN} = Ae^{Bt} + C$ with sample points n = 3, 4, 5, 6, 8, 14, 20, 30, respectively. The fitting method is the Gass least square method. The fitting results of the EM and IP effects when $n = 8$ are listed in Table 1 and Table 2. The fitting results with the other sample points have the similiar conclusions.

From these Tables, we can get the following conclusions:

(1) No matter how many fitting points are, the fitting results of the attenuation curves of the EM effect with different sample points are ideal, especially as to the main part of the EM effect attenuation curves($n \leqslant 8$), its fitting relative error is less than 1.2%. Therefore, we can consider that the attenuation curve of the EM effect can be fitted by a single exponental curve under the homogeneous semi-infinite space. To the layer medium, the attenuation curve of the EM effect can be fitted by a single exponential function (results in Table 3) although discrete filter algorithm will cause some fitting error.

(2) In the fitting function, C reflects the normal field value when EM effect has almost attenuated and C is stable($2.1 \sim 2.2 \times 10^{-3}$) when the number of points is increased. B is a negative attenuation constant which reflects the EM effect's time constant. The larger the absolute value of B, the smaller the time constant. With the increasing of the fitting points, the absolute value of B slightly descends. This is equivalent to smooth the fitting curve up, or to say, the normal field for fitting increases; and A is positive, with the increasing of the fitting points, A is stable,

Table 1 The fitting results of the attenution curve of the EM effect on the surface of homogeneous earth

Times /ms	Measured values ($\times 10^{-3}$)	Fitted values ($\times 10^{-3}$)
0.00	5.683	5.680
6.28	2.899	2.921
12.6	2.321	2.295
18.9	2.180	2.153
25.1	2.129	2.121
31.4	2.102	2.114
37.7	2.098	2.112
44.0	2.093	2.112
$A = 3.6 \times 10^{-3}$	$B = -236.0$	$C = 2.1 \times 10^{-3}$

Table 2 The fitting results of the attenution curves of the IP effect on the surface of homogeneous earth

Times /ms	Measured values ($\times 10^{-3}$)	Fitted values ($\times 10^{-3}$)
0.00	1.400	1.413
2.40	1.497	1.470
3.60	1.519	1.518
7.20	1.512	1.560
9.70	1.638	1.596
12.1	1.595	1.626
14.5	1.66	1.651
16.9	1.675	1.673
$A = -0.4 \times 10^{-3}$	$B = -67.32$	$C = 1.8 \times 10^{-3}$

Table 3 The fitting results of the attenution curves of the EM effect on the surface of three layered earth

Times /ms	Measured values($\times 10^{-3}$)	Fitted values ($\times$ $^{-3}$)
0.00	34.29	34.29
7.90	11.94	11.99
15.7	7.256	7.118
23.6	5.920	6.053
31.4	5.749	5.820
39.3	5.707	5.769
47.1	5.723	5.758
$A = 2.85 \times 10^{-2}$	$B = -193.6$	$C = 5.8 \times 10^{-3}$

Parameters of the three layered earth: $\rho_1 = 100\,\Omega m$, $\mu_2 = 0.1$, $\mu_3 = 4$, $h_1 = 100\,m$, $\nu_2 = 2$

which is equivalent to the maximum of the pure EM effect.

(3) To the IP effect, both A and B are negative, and C is positive. In the expression, C expresses the potential value when the charge reaches saturation. B is the charge constant which is equivalent to the reciprocal of the time constant. Compared with B value of the EM effect, the absolute value of B of the IP effect is much lower. This indicates that the time constant of the IP effect is much higher than that of the EM effect. A is negative, which is equivalent to the difference between potential and C when the charge just begins. To the discharge curve, A is a positive one.

(4) In Table 2, the maximum relative error of fitting is 2.5%. But the fitting with 8 point does not completely reflect the main part of the IP charge curve. If the number of the fitting points is increased, the fitting error is obviously increased, and A, B, and C are unstable.

So the charge and discharge curves of the IP effect can not be fitted by a single exponential function. Because the IP effect reflects a complex electrochemical process, and has many influence factors, it must be fitted by a suitable multi-source model. Although that, when some of the characteristics of IP effect are being discussed, the superposition with a single exponential function or multi-exponential function are still used to fit the IP effect. We can not only simplify the problem, but also keep the generality.

Direct calculation in the time domain can also be used to study the varying laws of the IP and EM effects and similar conclusions can be deduced, but here we will not repeat them.

4 SPECTRUM OF PURE EM EFFECT IN DUAL-FREQUENCY WAVE

As regards to the dual-frequency wave form shown in Fig. 1(a), we subtracted the primary field from it and made Fourier analysis, then obtaind the spectrum of the pure EM effect shown in Fig. 4. To the dual-frequency wave, we knew from formula (1), at the frequency points with interest, supposing the amplitude of the fundamental wave is 1, then the amplitudes of the 3, 13, and 39 times harmonic waves are 1/3, 12/13, and 12/39, respectively. But in Fig. 4, the amplitudes of the pure EM effect at the frequencies mentioned above are 1, 1/3, 2.5, 2.5 respectively. Therefore, the pure EM effect will be strengthened with the increasing of frequency and would be related to the primary field.

We can see from Figs. 1~3 and analysis above that in any measured wave forms there is obviously difference between the EM and IP effects. The EM effect mainly concentrates in the sharp pulse at the rising and the descending edges of the mesured wave forms. Its high frequency composition is abundant. The IP effect is mainly a slow charging and discharging process. Its low frequency composition is also abundant. Therefore, we can remove the primary field and the sharp pulse which is affected by the EM effect from the measured wave form, then the field without the EM effect can be obtained, as shown in Fig. 5. This method is named "the chopping wave decoupling method". Obviously, this decoupling method is a direct one, it does not need any extra field work and indoor calculation. Therefore, it is a feasible, simple, quick and direct decoupling method, but the application of this method depends on the chopped wave width. As shown in Fig. 6, the IP effect is also partly lost when

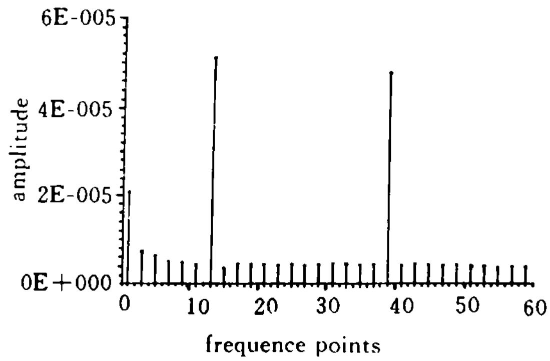

Fig. 4 The pure EM spectrum of the measured dual-frequency voltage wave

the EM effect is removed by this method. The degree of loss is controlled by width of the chopped wave . If the EM effect could be removed completely, the chopped wave width should be large, and the more IP effect will be lost. On the contrary, the narrower the width of chopped wave, the lesser the IP effect will be lost, but the EM effect can not be removed completely. So, it is ambivalent to select the chopped wave width. In the following, we shall discuss the decoupling effect which affects to the IP effect, applying conditions and the selection of the chopped wave width of the chopping wave decoupling method by numerical calculation and model experiments.

5 THE EVALUATION OF CHOPPED WAVE DECOUPLING METHOD

To the measured dual-frequency wave

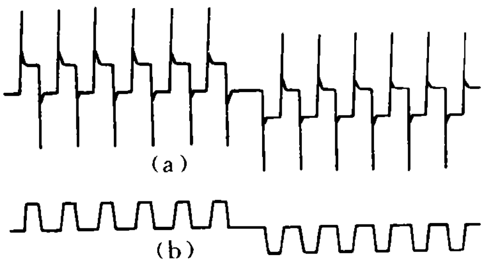

Fig. 5 Illustration of the chopping wave decoupling method

(a)—The waveform before wave chopping; (b)—The waveform after wave chopping

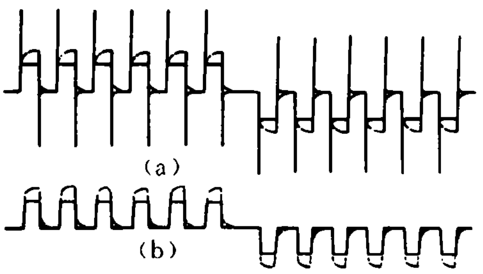

Fig. 6 Illustration of the decoupling effect and its influence on the IP effect of the chopping wave method

(a)—The waveform before wave chopping; (b)—The waveform after wave chopping

form in which EM and IP effects are existed (Fig. 1(c)), when high frequency half-cycle is consistaed of 20 discrete points, of which 1, 2, 3, 4, 5 points at the rising and descending edge are erased, respectively, then Fourier analysis were used to obtain the amplitude spectrum, the result is shown in Fig. 7.

In order to discuss the decoupling effect of the chopping wave decoupling method, and its affection on the IP effect, the Percent Frequency Effect (F_S) is calculated by the high and the low frequency amplitudes. The results are listed in Tabs. 4 to 6. Because of the chopping wave effect, the amplitude of primary field will be decreased, it must be compensated and normalized using the amplitude of corresponding frequency which is obtained by Fourier analysis after the corresponding width is chopped on the supplying current wave. Then the formula

$F_S = [(\Delta V_D - 13\Delta V_G/12)/\Delta V_D] \times 100\%$

is used to calculate F_S values.

In Tabs. 4~6, F_S in frequency domain is -8.81% when EM effect existed, 14.91% when IP effects existed, and 4.98% when both EM and IP effects existed.

According to Fig. 7, we can obtain:

(1) On macroscopic view, with the increasing of the chopped wave points, the amplitude of the EM effect obviously descends. It happens mainly to the fundamental wave, 3, 5, 7, 9, 11, 13 and 39 times harmonic waves. In addition, because of the affection of the chopping wave and errors in calculation, the amplitudes of the EM effect of the 25, 27,

Table 4 The decoupling effect of the chopping wave method when EM effect existed only

chopped points	Amplitude of waves($\times 10^{-3}$)			
	after chopping		after nomalization	
	f_D	f_G	f_D	f_G
0	1.633	1.646	1.631	1.646
1	1.551	1.529	1.632	1.534
2	1.470	1.486	1.632	1.523
3	1.388	1.476	1.632	1.518
4	1.307	1.439	1.632	1.514
5	1.225	1.395	1.632	1.510

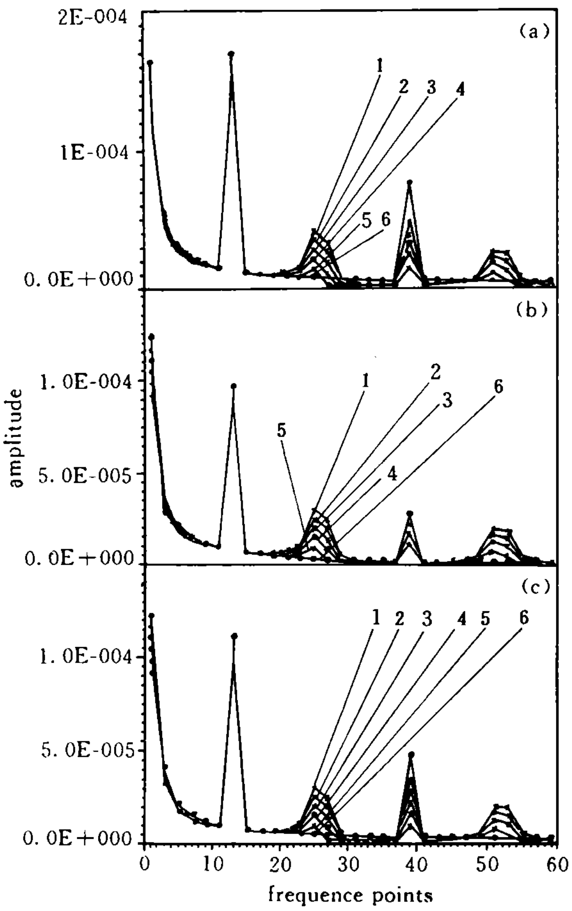

Fig. 7 The spectrum of the measured dual-frequency voltage wave after wave chopping

(a)—only for EM effect; (b)—only for IP effect; (c) —for both EM and IP effects existed; 1— no point chopped; 2—1 point chopped; 3—2 points chopped; 4—3 points chopped; 5—4 points chopped; 6—5 points chopped

Table 5 The decoupling effect of the chopping wave method when both EM and IP effects existed

chopped points	Amplitude of waves($\times 10^{-3}$)			
	after chopping		after nomalization	
	f_D	f_G	f_D	f_G
0	1.229	1.072	1.229	1.072
1	1.169	1.014	1.231	1.017
2	1.109	0.991	1.232	1.003
3	1.048	0.973	1.232	0.996
4	0.986	0.944	1.232	0.996
5	0.925	0.920	1.232	0.993

Table 6 The decoupling effect of the chopping wave method when IP effect existed only

chopped points	Amplitude of waves($\times 10^{-3}$)			
	after chopping		after nomalization	
	f_D	f_G	f_D	f_G
0	1.231	0.9665	1.231	0.9965
1	1170	0.9638	1.231	0.9668
2	1.109	0.9615	1.232	0.9735
3	1.048	0.9525	1.232	0.9798
4	0.9867	0.9375	1.232	0.9858
5	0.9255	0.9158	1.232	0.9911

51, 53 times harmonic waves are increased.

(2) With the increasing of the chopped wave points, the amplitude of the fundamental wave generally decreases linearly, but the amplitude of the 13 times harmonic wave does behave in this way. It decreases unobviously except when the EM effect exists(Fig. 7(a) and Fig. 7(c)) and 1~2 points are chopped. With the continuous increasing of the chopped wave points, it decreases a little quickly. That is to say, with the increasing of the chopped wave width, the amplitude of total field of the fundamental frequency and the high frequency decreases in different scales. The reason is shown in Fig. 8 which illustrats the measuring results of the high and the low frequency real components in practice. They are obtained respectively by integrating the conducts of the sine waves in Fig. 8(b), (c) with the dual-frequency wave in Fig. 8(a). The shadows in the figures are the chopped parts. Obviously, the chopped parts to the high frequency wave is actually the over-zero part of the primary field. But to the low frequency wave, the chopped parts are much more than that of the high fnequency wave, the attenuation of the low frequency primary field is much stronger than that of the high frequency.

(3) Because of the existence of the EM effect, the amplitude of the total field(including the EM effect) is larger than that of the low frequency although the high frequency primary field is only 12/13 of that of the low frequency,. With the increasing of the chopped wave points, the fundamental wave

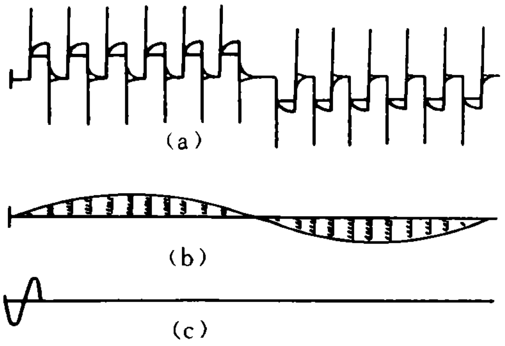

Fig. 8 Illustration of the measurement results of the real components and the influence of the chopping wave on the reals

(a)—The measured waveform; (b)—Measuring of the real of the low frequency wave; (c)—Measuring of the real of the high frequency wave

decreases linearly, which indicates that the EM effect has less affection to the fundamental wave and most of primary field is chopped. But to the high frequency, when 1～2 points are chopped, its amplitude obviously decreases, and with increasing of the chopped wave points, its affection is not obvious. This indicates that the EM effect obviously appears at the rising and descending edges of the high frequency wave. It shows the obvious decoupling effects at the same time.

(4) In Fig. 7(c) in which two kinds of effects were illustrated, the law is almost the same as that in Fig. 7(a). Because of the existence of the IP effect, the low frequency amplitude increases a little comparing with the high frequency amplitude. This shows that the IP effect mainly exists in the low frequency composition.

(5) From Fig. 7(b) where only the IP effect is illustrated, the low frequency amplitude is obviously larger than that of the high frequency before wave chopping. Since the IP effect is weak in the high frequency, the effect of wave chopping on the high frequency amplitude is small, the low frequency amplitude(including the primary field and the IP effect) decreases obviously.

(6) Under the three cases, with the increasing of the chopped wave points, attenuation of the 39 times harmonic wave is very obvious, and it is the strongest when there is only the EM effect. It is the second when both the IP effect and the EM effect exist. It is the weakest when there is only the IP effect. This shows that the EM effect has large contribution to the 39 times harmonic wave, and the decoupling effect is obvious.

We can obtain the following conclusions from F_S calculated in above Tables:

(1) Compared with theoretical values of F_S, the numerical calculation results are corrrect and have high precision. When the EM effect is existed(Tab. 4 and Tab. 5), because it has a large contribution to the high frequency, truncation error caused by the definite high frequency cut-off frequency in numerical calculation makes the absolute error between F_S and the theoretical value up to 0.45%.

(2) When there is only IP effect, the result of numerical calculation is identical with the theoretical value.

(3) We know from Tabs. 4 and 5, that the EM effect can be removed very well when the chopped wave points are 3～4. At this time, the effect of the residual EM effect is less than −1%, and F_S is close to the F_S value (Table 6) which is obtained when only the IP effect is existed. This shows the decoupling effect of the method is obvious.

(4) The IP effect decreases with the increasing of chopped wave points, when the chopped wave point is 5 F_S is only 86.34% of that before wave chopping.

From analysis above, we can see that generally when 1/5～1/10 of the high frequency half-cycle is chopped at the rising and descending edges of high frequency half-cycle, satisfied decoupling effect can be obtained, and the IP effect will not be over lost. In addition, the decoupling effect on the high frequency is more obvious, and the primary field and the IP effect attenuate only a little. On the contrary, it also makes the primary field and the IP effect over decreasing although it has the same decoupling effect to the low frequency.

Under the general circumstances, the

chopping wave decoupling method can get satisfying decoupling effect and cause less loss of the IP effect. If the EM effect would be removed when there is slight difference between the time constants of the IP and EM effects, the IP effect will be lost a lot. This is the limitations of the method.

It is certain that the chopping wave decoupling method is a very good decoupling method in resistivity measuring. The microsounding instrument developed by the authors is designed using this mehod to remove the EM effect, and very good application effects have been obtained. In the "Anti-coupling dual-frequency IP instrument", the same method is also adopted to remove the EM effect. As an unique direct decoupling method applied in field, it is a simpler, quicker and more direct method to remove the EM effect than other data processing methods. However, its limitations should also be paid attention to in practice.

6 THE MODEL EXPERIMENT RESULT AND PRACTICAL APPLICATIONS

The anti-coupling dual-frequency digital IP instrument designed on the chopping wave decoupling method obtained very good decoupling effect in many areas. In the following we shall simulate the EM effect in field by a RC circuit. The simulation circuit is shown in Fig. 9.

On this simulation circuit, the DBJ — 1 variable frequency instrument, the S—1 dual-frequency IP instrument, and the S — 3 anti-coupling dual-frequency IP instrument were used to compare the decoupling effect. The results are listed in Table 7. We see from Tab. 7 the F_S value mearsured by the anti-coupling dual-frequancy instrument is less than -1% although the RC circuit causes very large F_S value. So the decoupling effect is rather obvious.

Fig. 10 shows the result of an experiment done at an old flood land 30 km away from Baoding. The flood land is flat and is covered

Tab 7 Comparison of experimental results

$C_1 = C_2$	$R_1 = R_2$	DBJ—1	S—1	S—3
0.47 μF	100K		−0.9%	−0.1%
0.10 μF	100K		−2.4%	−0.1%
0.22 μF	100K	−10.3%	−10.1%	−0.2%
0.33 μF	100K	−18.7%	−22.7%	−0.8%

by tiny sands with resistivity of about 10 Ωm. Adopting gradient array: AB=1400m, MN=160 m, comparative observations at the same point were carried out using J — 74B variable frequency instrument and S — 3 anti-coupling dual-frequency IP instrument. With increasing of AB very high negative percent frequency effect caused by EM effect was observed by J — 74B, but the value measured by S — 3 is much lower, so the decoupling effect of the S — 3 is obvious.

Fig. 11 shows a testing profile in Wuhu. This area is covered by the Quaternary of 40m in thickness. The resistivity is 30～120 Ωm. F_S curves measured by the D660 variable frequency instrument was completed in 1978 — 1979. The curves measured by the S—3 anti-

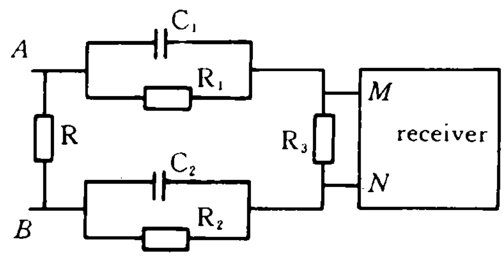

Fig. 9 RC circuit for simulating EM effect

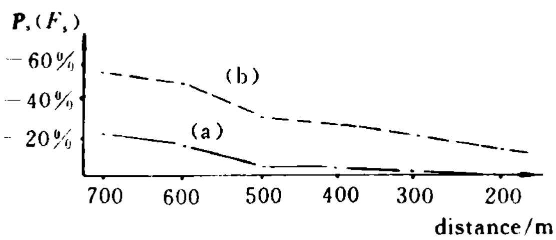

Fig. 10 Comparison of the observation results with different IP instruments when the EM effect existed

(a)— F_s curves measured with S-3(0.3/3.9HZ);
(b)— P_s curves measured with J-74B(0.46/4.6HZ)

coupling dual-frequency instrument was done in 1983. There is a time gap of four years between the two observations, and there are a lot of change in subsurface. For example, underground water pipes were laid under the measuring site. From the figure, we can see the anti-coupling dual-frequency instrument still obtained obvious decoupling effect.

7 CONCLUSIONS

A direct, simple, quick, feasible chopping wave decoupling method is advanced in this paper. The method is not only suitable to the dual-frequency IP method, but also suitable to the variable frequency method and resistivity method. The decoupling effect, the affection to the IP effect and the applying conditions of the chopping wave decoupling method have been evaluated by numerical calculation method in this paper. Type C－1, C－2 micro-sounding instruments designed on the base of this method have obtained very good geological effect in practical application. The anti-coupling dual-frequency digital IP instrument designed on the base of this method has obtained very good decoupling effect under

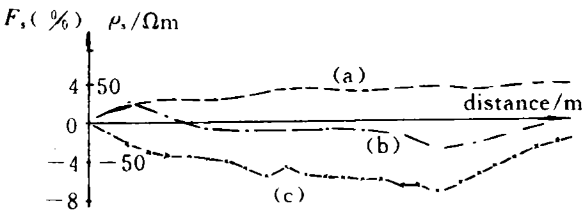

Fig. 11 Comparison of the observation results with different IP instruments when EM effect existed

(a)—ρ_s curves measured with the S-3; (b)—F_s curves measured with the S-3(0.3/3.9HZ); (c)—F_s curves measured with the P660 (0.3125/5.0HZ)

most geological circumstances.

In practice, when there is a great difference between the time constants of the IP effect and the EM effect, as long as 1/10～1/5 of the half-cycle is chopped at the rising and descending edges of the measured wave form, obvious decoupling effect can be obtained and the IP effect is not over lost. But, when the time constants of the EM effect and the IP effect are slightly different, the IP effect has also been lost much, if the EM effet is removed by this method. This is the limitation of this method in practice.

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