SQUARE WAVE COHERENT METHOD FOR EXTRACTING IP EFFECT[①]

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ABSTRACT Using special appearance of EM and IP effects in measured dual-frequency wave form, a square wave coherent method to extract IP effect directly and simutaneously was proposed. The results of numerical calculation and experiments showed that EM effect can be eliminated well in field measurement. The instrument made on this method worked well in waterbath experiments.

Key words: dual-frequency IP method square wave coherent method Fourier coherent methed EM effect IP effect

1 PRINCIPLE OF SQUARE WAVE COHERENT METHOD

Generally, the so called "Fourier coherent method" is used to measure the electromagnetic field. Supposing the measurement signal is presented by $f(t)$, then its real and imaginary part get by Fourier coherent method are respectively as follows:

$$\mathrm{Re}(f) = \int_0^T f(t)\cos\omega t\,dt \tag{1a}$$

$$\mathrm{Im}(f) = \int_0^T f(t)\sin\omega t\,dt \tag{1b}$$

where $Re(f)$ and $Im(f)$ stand for the real and imaginary part of signal $f(t)$. $\omega = 2\pi/T$, T is the period of signal $f(t)$.

Correct IP effect can be gotten by Fourier coherent method when there is no EM effect, but the result of Fourier coherent method could be affected seriously by EM effect, so new method to extract IP effect when there is EM effect must be studied.

Fig. 1(a) is the measured dual-frequency wave form when both EM effect and IP effect exist. According to electromagnetic induction law, EM effect is produced only when the current is changed, so it exists only at the rising and descending edges of the wave forms. If the wave form in Fig. 1(a) is multiplied by a square wave whose frequency and phase are the same as those of the low-frequency wave in the dual-frequency wave (that is called "square wave coherence"), the wave form in Fig. 1(b) can be obtained, then the real part of low-frequency wave, represented by $Re(D)$, can be get by integrating. Similarly, we can get the imaginary part of low-frequency wave, represented by $Im(D)$. The amplitude ($A(D)$) and phase($\varphi(D)$) of the low-frequency wave can be calculated using real and imaginary part. Generally, $Re(D) \gg Im(D)$, so $A(D) \approx Re(D)$.

From Fig. 1(b) we can get that the amplitude of EM effect at the rising edges is equal to that at the descending edges, but the sign of them is opposite. So the amplitude of EM effect after integrating is equal to zero. In the contrary, the IP effect is enhanced after integrating becauce the signs of IP effect at the rising and descending edges are the same. Namely there are only the primary field and IP effect in $Re(D)$. Similarly, the EM effect is not contained in $Im(D)$, and IP effect in $Im(D)$ is also weak.

According to above discussion, for one supply, $Re(D_1)$ and $Im(D_1)$ which include no EM effect are gotten, then $A(D_1)$ and $\varphi(D_1)$ can be computed. Decreasing the frequency of

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dual-frequancy current and repeating above measurement, $Re(D_2)$, $Im(D_2)$, $A(D_2)$ and $\varphi(D_2)$ *are obtained*; and then spectrum data can also be obtained by changing the supplying frequencies. The percent frequency effect(F_S) is computed as follow:

$$F_S = \frac{A(D_2) - A(D_1)}{A(D_2)} \times 100\% \qquad (2)$$

2 FEASIBILITY OF THE METHOD

Through theoretical calculation and numerical simulation, the following questions were investigated: (1) when both IP and EM effects exist, how about the decoupling effect of the square wave coherent method is? (2) what is the difference between the results obtained by the square wave coherent method and by the Fourier coherent method? (3) can all the observation schemes get rid of the EM effect by using the square wave coherent method?

As shown in Fig. 2, a RC subcircut is considered as the simplest cole-cole model to simulate IP effect. Meanwhile, a RL subcircut is used to simulate EM effect. Model parameters are: $R_1 = 200\,\Omega$, $C = 200\,\mu F$, $R_2 = 2\,000\,\Omega$, $L = 1$ H. So the largest percent frequency effect of the IP effect is 200/(200+2 0 0 0) × 100% = 9.1%. The complex impedance between MN can be expressed as

$$R_{MN} = \frac{R_1R_2 + \frac{L}{C} + \frac{R_2}{i\omega C} + iR_1\omega L}{R_1 + R_2 + \frac{1}{i\omega C} + i\omega L} \qquad (3)$$

For $L = 1$ H and $L = 0$ respectively, the complex impedance amplitudes are calculated and listed in Table 1. Note that in Tab. 1, the result obtained by Fourier coherent method is amplitude, but it is the real part in square wave coherent method. From the Table 1 it is known that:

(1) When EM effect is relative weak($f < 1$ Hz), for either the Fourier or the square wave coherences, the F_S obtained when EM effect being existed is very close to that of without EM effect. The biggest absolute error between them is only about 0.3%, which includes the numerical calculation error and the error in the amplitude which is approximately equals to the real part. This ensures that the IP anomaly obtained by the new method is identical to the results of other methods.

(2) When EM effect is relatively strong ($f < 10$ Hz), the results of Fourier coherent

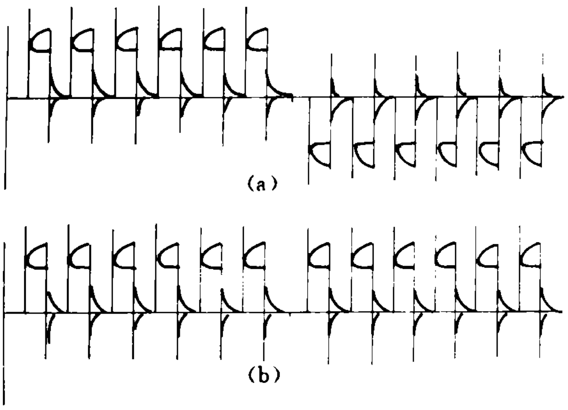

Fig. 1 Illustration of the square wave coherent method
(a)—The waveform before coherent
(b)—The wayeform after coherent

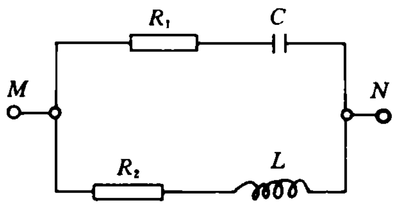

Fig. 2 The RLC network to simulate EM effect and IP effects

Table 1 The calculated results of compedance

f	Amplitudes calculated with Fourier method		Real part in square wave coherent
	$L = 0$	$L = 1$	
0.001	200.00	200.00	200.00
0.01	199.99	199.99	200.01
0.1	198.76	198.78	199.34
1	184.01	184.27	184.63
10	181.84	189.71	182.20
100	181.82	576.89	182.70

method are affected obviously by EM effect, But the results of the square wave coherent method($F_S \approx 8.9\%$) is close to the theoretical result($F_S = 9.1\%$) without EM effect. So the square wave coherent method can eliminate EM effect well in most case.

(3) When EM effect is very strong($f \geqslant 10$ Hz), the results of Fourier coherent method can not indicate the existence of IP anomaly. At this case, the false F_S value caused by EM effect is up to -200%, which covers IP effect completely. In the contrary, the F_S value obtained by square wave coherent methed is about 8.7% which is little difference from the theoretical value(9.1%), and can be used to indicate IP effect. Thus, even at the extreme case, the square wave coherent method can obtain IP anomaly containing little EM effect.

Now, using square wave coherent method, the real components of single-frequency square wave and dual-frequency square are obtained wave and listed in Table 2.

Table 2 The real components measured by square wave coherent method($\times 10^{-3}$)

	Single-frequency	Dual-frequency
IP	4.556	4.414
EM	4.668	4.134
EM+IP	4.856	4.426

When both EM effect and IP effect being existed, and if the EM effect can be removed by the square wave coherent method, the integral results should be the same as the result obtained when there is only the IP effect.

In the Table 2, for the dual-frequency wave, the error is $(4.426-4.414)/4.414 = 0.27\%$, whereas to the single-frequency wave, the error is $(4.856-4.556)/4.556 = 6.5\%$. This indicates the square wave coherent method can achieve very good decoupling effect to the dual-frequency wave, whereas to the single-frequency wave the square wave coherent method can not obtain ideal decoupling effect. So the square wave coherent method is a distinctive and direct decoupling method in the dual-frequency IP method.

3 EXPERIMENT RESULTS

According to the method above and based on the F－1 dual-frequency spectrum IP instrument, a dual-frequency decoupling spectrum IP instrument temporarily named as the F－2 spectrum IP instrument has been developed, network experiments and water-bath experiments have been carried out. Some experiment results are discussed in the follows.

The RLC network used to simulate the situation when both IP effect and EM effect being presented in experiment was the same as in Fig. 2, where $R_1 = 3$ K, $C = 50\,\mu$F; $R_2 = 10$ K, $L = 820$ mH. When L or C is in short-circuit, it can be used to simulate the situation when there is only IP or EM effect.

Fig. 3 shows the curves of percent frequ-

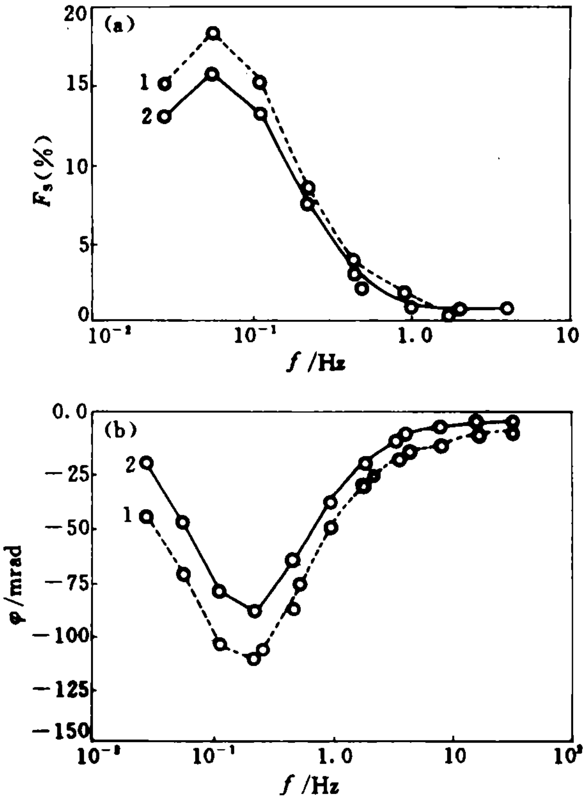

Fig. 3 Experiment results when IP effect existed only

1—measured by F－1; 2—measured by F－2;
(a)— F_S ; (b)—phase

ency effect and phase measured by F—1 and F — 2 dual-frequency spectrum IP instruments when there is only IP effect. It can be seen that, for not only the percent frequency effect curves but also the phase curves, the results obtained by the two instruments are very close, and the curve forms are identical. Although the anomaly observed using F — 1 is little stronger than that of using F—2 and is caused by different frequency difference in two instruments which is 9 times in F—1 and only 8 times in F — 2, there is no essentlal difference for reflecting IP anomaly between the square wave coherent and Fourier coherent method.

Fig. 4 and 5 show the experiment results when EM effect existed. Comparing to the curves in Fig. 3, the results measured using F —1 are contaminated by EM effect seriously, whereas the results observed using F—2 is basically not affected by EM effect. In Fig. 4, because there is no IP effect, the curves of percent frequency effect and phase measured using F — 2 are almost straight lines whose values are close to zero. In Fig. 5, although both EM effect and IP effect are presented, the results observed using F—2 are in good agreement with that when there is no EM effect.

Some experiments are carried out in a big water tank in order to simulate the field circumstance. The arrangement used is shown in Fig. 6. When K_1 and K_2 are turned off, because the current electrodes spacing AB is

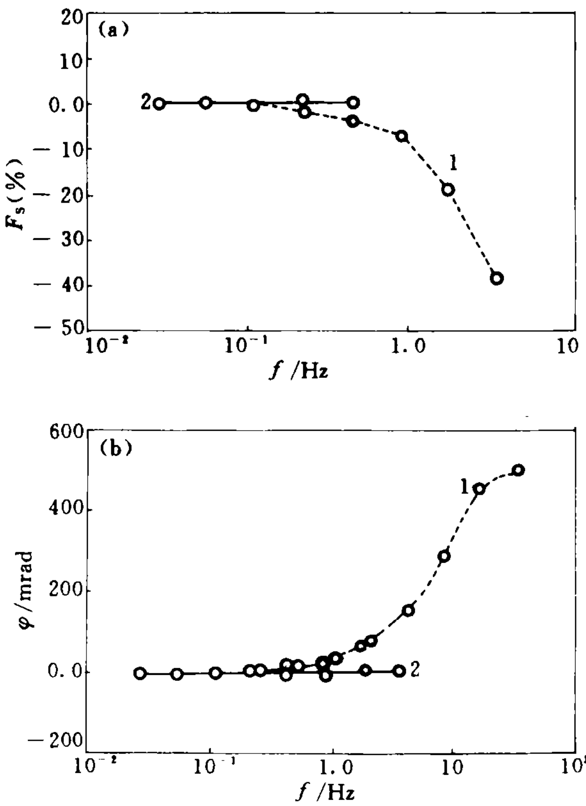

Fig. 4 Experimental results when EM effect existed only

(a)— F_S ; (b)—phases;

1—measured by F—1; 2—measured by F—2

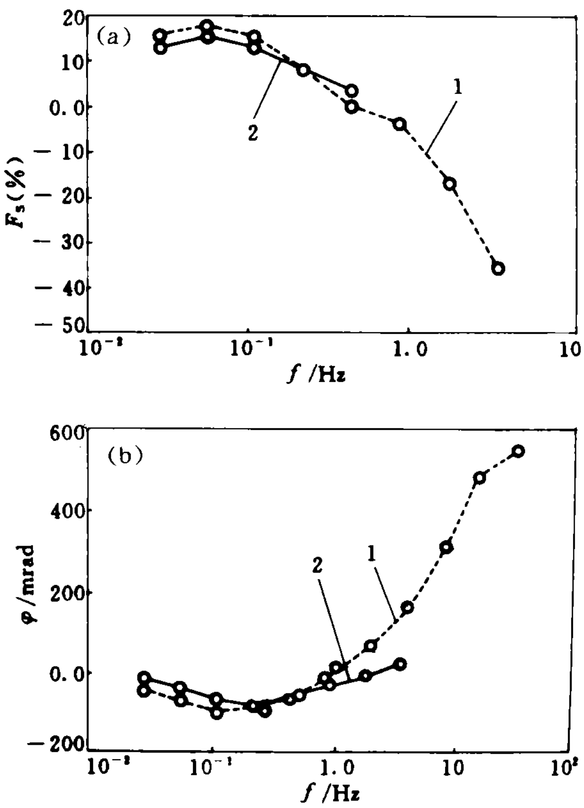

Fig. 5 Experimental results when both EM and IP effects existed

(a)— F_S ; (b)—phases;

1—Measured by F—1; 2—Measured by F—2

very small, the EM effect will be very weak, and the anomaly is only the IP effect of the chalcopyrite. When K_1 and K_2 are turned on, let $C_1 = C_2$, $R_1 = R_2$ which can vary arbitrarily so that they can be used to simulate the strength or weakness of the EM effect in different stations.

Fig. 7 shows the spectral curves of percent frequency effect measured at station No. 51. When EM effect is presented (Fig. 7(a)), strong negative values are observed by F−1 with increasng of frequency. This is caused by EM effect. However, the results of F−2 are in good agreement with that of no EM effect (Fig. 7(b)). Same conclusion could be drawn from phase curves.

Finally, profile measurement was carried out in the water-tank. The frequencies used in F−1 are 4/9 and 4 Hz, whereas to F−2 those are 0.5/4 Hz. The profile results are shown in Fig. 8. Because of the action of strong EM effect, the results measured by F−1 almost can not reflect the existence of the IP anomaly which is produced by the polarization body. But the results measured by F−2 can extract the IP effect from the total field very well.

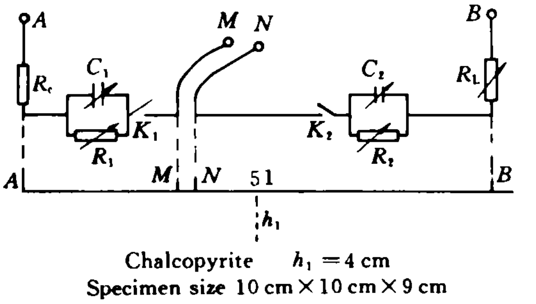

Fig. 6 Arrangement of water-bath experiments

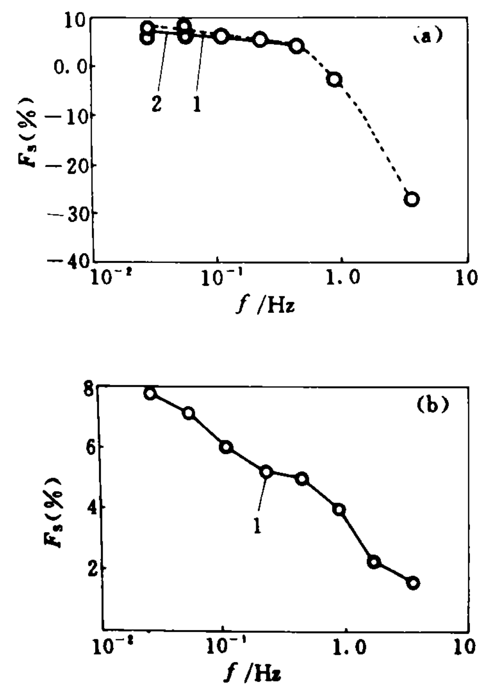

Fig. 7 Experiment results of F_S effect (a) and phase (b) in water-tank

1—Measured by F−1; 2—Measured by F−2

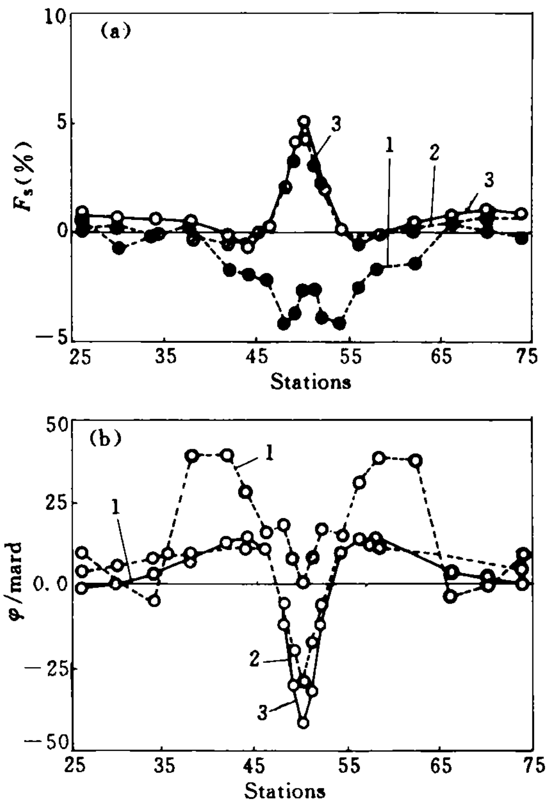

Fig. 8 Profile results measured in water-tank

(a)— F_S; (b)—phase

1—Measured by F−1; 2—Measured by F−2

3—Measured by F-1 (without EM effect)

The anomaly form and value are very close to the results measured by F—1 when there is no EM effect. The difference between them comes mainly from the frequency difference, errors in observation, etc. This can prove that the square wave coherent method is feasible in the dual-frequency IP method, and it can supress EM effect very well.

4 CONCLUSIONS

Square wave coherent method, extracting IP effect from total field directly and eliminating EM effect well, is proposed. The basis of this method is the electromagnetic induction law and the specially measured wave forms of dual-frequency IP metod, so this methed is suitable to general geological environment. Moreover, when there is very strong EM effect, IP anomaly containing little EM effect could also be obtained using square wave coherent method. Instrument designed on this method has obtained good effect in water-tank experiments and can be applied in the field.

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