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Isomorphic Emphasis in Spectrum Inversion over Existing Analog Speech Channels

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送受同形エンファシスのスペクトラム反転秘話への適用

岸　政七

Accompanying social advances and diversification, more and more utility is being found for automobile, airplane and other types of mobile telephones. The user of these mobile communication systems finds merit in being able to place and receive calls whenever or wherever he wants. However, since the communication of these calls is carried by radio waves, it is easy to eavesdrop on them, placing their confidentiality in jeopardy.

To overcome this demerit, the idea of adding an encryption function to radio comunications has been studied from various approaches. However, as is common with most radio communication systems to which an encryption function has been added, the spectrum scrambler requires sacrifice in speech quality. The increase of effective modulation deviation produced in the spectrum scrambling process is a major cause of transmission SNR degradation. The larger this effctive PM index, the wider the frequency bandwidth occupied by the radio carrier becomes.

Therefore, it is necessary to avoid this increase in effective PM index when providing an encrytion function to communication systems. In order to guard against effective PM index increasing from spectrum scrambling, conventionally it has been necessary to suppress the input signal level by more than 10dB (in power). Therefore, irrespective of whether scrambling is carried out or not, or to its properties, the SNR characteristic will degrade relative to fading noise at a fixed level or in inverse proportionate to the input signal level.

This study has shown the exsitence of a new type of emphasis for spectrum inversion — hereafter called "Isomorphic Emphasis" — in which effective PM index of the arbitrary signal is always maintained equal with non-encrypted effective PM index and in which the sending and receiving emphasis are also equal. The findings of this study are quantitatively discussed. Furthermore, an equal sending and receiving emphasis characteristics means that repeatability in the manufacturing of the emphasis circuit can be increased and manufacturing costs reduced. At the same time, it also means that a pre-emphasis circuit for sending and a de-emphasis circuit for receiving can be used together in simplex (press to talk) communication sytem.

1. INTRODUCTION

Accompanying social advances and diversification, more and more utility is being found for automobile, airplane and other types of mobile telephones in both our private and business activities. In fact, it has been remarkable where popularization of these systems over recent years. The user of these mobile communication systems finds merit in being able to place and receive calls whenever or wherever he wants. However, since the communication of these calls is carried by radio waves, it is easy to eavesdrop on them, placing their confidentiality in jeopardy.

To overcome this demerit, the idea of adding an encryption function to radio communication has been studied from various approaches. One such example centers on spectrum inversion, which NTT has already put to practical use in its "Automated Marine Telephone System" [(1),(2)]. The spectrum scrambler, used for spectrum inversion in this system, tends to a bit complexed and high priced. Differing from time-domain scrambling, though, it does not require such synchronization as bit and frame and can be used with existing analog telephone networks. Therefore, it offers the advantage of lower cost when viewed from overall network provisioning.

However, as is common with most radio com munication systems to which an encryption function has been added, the spectrum scrambler requires sacrifice in speech quality. The root of this problem is not in the scrambler itself, but rather in the increase of modulation deviation produced in the spectrum scrambling process, which, in turn, is a major cause of transmission SNR degradation.

The degree of effective modulation in phase modulation (abb. in PM) transmission is proportionate to the second order moment of the frequency of instantaneous power in the input signal[(3)]. The larger this effective PM index, the wider the frequency bandwidth occupied by the radio carrier becomes. Therefore, it is necessary to avoid this increase in effective PM index when providing an encryption function to a communication system. Effective PM index of the spectrum scrambled arbitrary signal should be proportionate to that without scrambled and increase generally. In order to guard against effective PM index increasing from spectrum scrambling, conventionally it has been necessary to suppress the input signal level by more than 10dB (in power). Therefore, irrespective of whether scrambling is carried out or not, or to its properties, the SNR characteristic will degrade relative to fading noise at a fixed level or in inverse proportionate to the input signal level.

This study has shown the exsitence of a new type of emphasis for spectrum inversion — hereafter called "Isomorphic Emphasis" — in which effective PM index of the arbitrary signal is always maintained equal with non-encrypted effective PM index and in which the sending and receiving emphasis are also equal. The findings of this study are quantitatively discussed in the following sections.

2. INFLUENCE OF SPECTRUM INVERSION ON EFFECTIVE MODULATION

This section examines the ration of effective PM index resulting from spectrum inversion. Fig.1 compares the spectrum of (a) a PM transmission system without spectrum inversion — hereafter called a non-encrypted PM transmission system — and (b) a spectrum inverted transmission system. Here, the phantom voice signal G'(f) specified in CCITT. REC-G277 is used as the generalized input signal.

The non-encrypted effective PM index Div'_{PM} for the transmission system shown in Fig.1 (a) — this modulation hereafter to be called non-encrypted PM — is expressed

$$Div'_{PM} = \int_{f_1}^{f_2} f^2 G'(f) df \tag{1}$$

Here, the instantaneous power $G'(f)$ of the generalized phantom voice signal is given

$$G'(f) = 1/(1+f^2/fc^2) \tag{2}$$

Where fc is the cut-off frequency. fc has been specified at 0.8kHz in CCITT. REC-G277 ; however, it is given a generalized value of $0<fc<\infty$.
Here, f_2 and f_1 are the supremum and infimum frequency of the input signal freqency band.

Substituting Eq.2 into the integrand of Eq.1 and expanding it to partial fractions, Div'_{PM} becomes

$$\begin{aligned} Div'_{PM} &= fc^2 \int_{f_1}^{f_2} \{1-fc^2/(f^2+fc^2)\} df \\ &= fc^2\{f+fc\tan^{-1}(fc/f)\} \Big|_{f_1}^{f_2} \\ &= fc^2\{fw-fc\tan^{-1}[(fw/f_G)/(fc/f_G+f_G/fc)]\} \end{aligned} \tag{3}$$

Here, fw means bandwidth : f_2-f_1, and f_G stands for geometrical mean : $\sqrt{f_1 f_2}$.

On the other hand, effective PM index Div'_{INV} in the spectrum inversion transmission system shown in Fig.1 (b) is expressed

$$Div'_{INV} = \int_{f_1}^{f_2} f^2 S'[G'(f)] df \tag{4}$$

Where, operation S' (∗) stands for spectrum inversion. For example

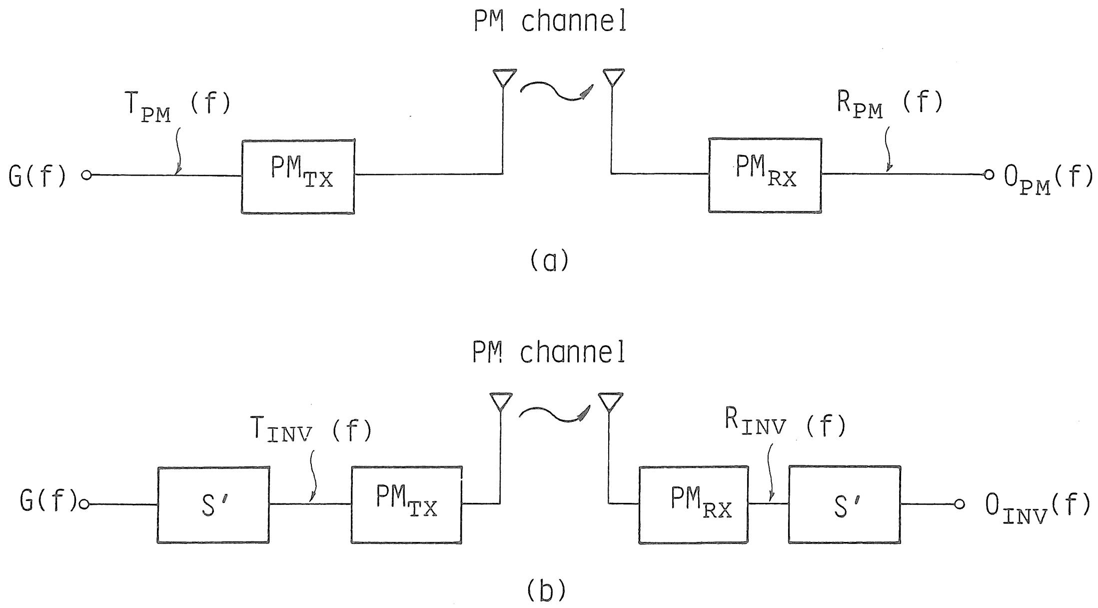

Fig. 1 Structural comparison of PM transmission systems, (a) existing PM transmission system, (b) PM transmission system with spectrum inversion function.

$$S'[G'(f)] = G'(fo-f). \qquad (5)$$

With fo as the pivotal frequency f_1+f_2 of spectrum inversion, the inverse function $S'^{-1}(*)$ of spectrum inversions $S'(*)$ is given

$$S'^{-1}(*) = S'(*) \qquad (1)$$

This is because

$$S'\{S'[G'(f)]\} = S'\{G'(fo-f)\} = G'(f), \qquad QED.$$

Substituting the phantom voice signal characteristics of Eq.2 into the integrand of Eq.4 and changing the variable x to fo-f, Div'_{INV} becomes

$$Div'_{INV} = fc^2\int_{f_2}^{f_1} (fo-x)^2/(x^2+fc^2)(-dx) \qquad (4)'$$

Setting the variable x to be f again and expanding the integrand of Eq.4 into partial fracrtions, Div'_{INV} becomes

$$Div'_{INV} = fc^2\int_{f_1}^{f_2} \{1+(fo^2-fc^2)/(f^2+fc^2) -2fof/(f^2+fc^2)\}\,df$$

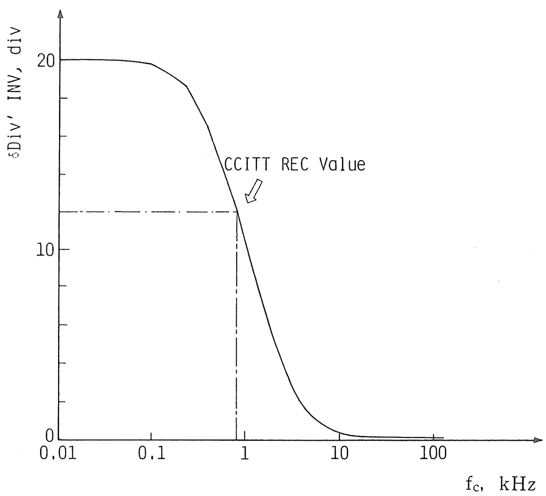

Fig. 2 Frequency response of $\delta Div'_{INV}$ in relation to fc

$$= fc^2\{f - fo(fo/fc - fc/fo)\tan^{-1}(fc/f) - fo\log(f^2+fc^2)\}\Big|_{f_1}^{f_2}$$

$$= fc^2\{fw + fo(fo/fc - fc/fo)\tan^{-1}[(fw/f_G)/(fc/f_G + f_G/fc)] - fo\log(f_2^2+fc^2)/(f_1^2+fc^2)]\}. \qquad (7)$$

The Eq.7 to Eq.3 ratio, namely the ratio of effective PM index, $\delta Div'_{INV}$ is found to be

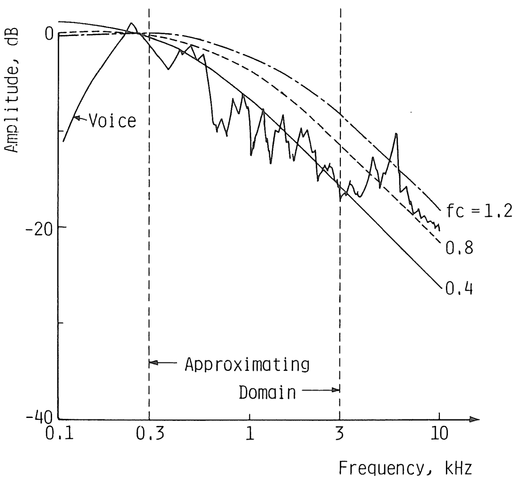

Fig. 3 Voice frequency response and its approximations

$$
\begin{aligned}
\delta Div'_{\mathrm{INV}} &= Div'_{\mathrm{INV}}/Div'_{\mathrm{PM}} \\
&= \{fw + fo(fo/fc - fc/fo)\tan^{-1}[(fw/f_G)/(fc/f_G + f_G/fc)] - fo\log(f_2^2 + fc^2)/(f_1^2 + fc^2)]\} \\
&\quad /\{fw - fc\tan^{-1}[(fw/f_G)/(fc/f_G + f_G/fc)]\} \qquad (8)
\end{aligned}
$$

Making the variable *fc* in the generalized phantom voice signal G'(f) a parameter, the value of δDiv'$_{\mathrm{INV}}$ is as shown as in Fig.2. In this figure, the horizontal axis indicates fc kHz and the vertical one indicates δDiv'$_{\mathrm{INV}}$ in dB.

It is clearly seen that δDiv'$_{\mathrm{INV}}$ has a value of 0 dB across the entire fc range, and that, more particularly, it jumps up to 12.0 dB at fc=0.8 kHz, which is the fc value specified in the CCITT. REC-G277.

Furthermore, as Fig.3 shows, approximation accuracy of the phantom voice signal is improved when the signal band is restricted to 0.3 to 3.0 kHz which is standard for automobile telephones, and the parameter fc of the generalized phantom voice signal is below 0.8 kHz. This fact suggests that the amount of increased effective modulation experted by spectrum inversion in radio communications exceeds 12 dB. In other words, when employing spectrum inversion the existing non-encripted PM system the input signal level must be attenuated by more than 12 dB for it to be used without modification. This is because the employment of spectrum inversion causes transmisson SNR to degrade. If the input signal level is not lowered to avoid this degradation, marked deterioration of speech quality will result in IDC (Instantaneous Deviation Controller), where the amplitude of the input signal to the modulator is restricted to keep the modulated wave within a fixed value and the input is clipped.

3. EFFECT OF EACH TYPE OF EMPHASIS ON EFFECTIVE MODULATION

Fig.4 illustrates the structure of (a) a PM transmission system with a spectrum inversion function, but employing no emphasis, (b) a spectrum inversion transmission system employing existing emphasis, and (c) a spectrum inversion transmission system employing the new isomorphic emphasis proposed in this paper. As discussed above, as long as signal is merely spectrum inverted and phase modulated, effective modulation will increase making it difficult to avoid speech quality degradation beyond the allowable value for effective modulation.

Without adopting the new emphasis, lowering the input level will reduce speech quality by more than 12 dB. This means that even when spectrum inversion is adopted, maintaining an arbitrary level of effective modulation is critical. Recently, studies have begun on the transmission system shown in Fig.4 (b), where in order to keep the degree of modulation from changing when spectrum inversion is employed, pre-emphasis of the input signal characteristic is performed and PM is carried out. This section will briefly review those studies and discuss the isomorphic emphasis which maintains an equal degree of deviation between PM of the arbitrary input signal and non-encripted PM.

3.1 Effective PM Index Spectrum Inversion System using Exisitng Pre-emphasis

The series of studies centering on maintaining an equal degree of deviation between transmission and non-encripted modulation when a spectrum inversion function is added have each specified the input signal to be the phantom voice signal shown in Eq.2, which is not sufficient condition for the arbitrary input signal, effective PM index Div'$_{\mathrm{EX}}$ for the phantom voice sigal G'(f) of a transmission system with a spectrum inversion function employing existing pre-emphasis can be given as follows[(4),(5)] :

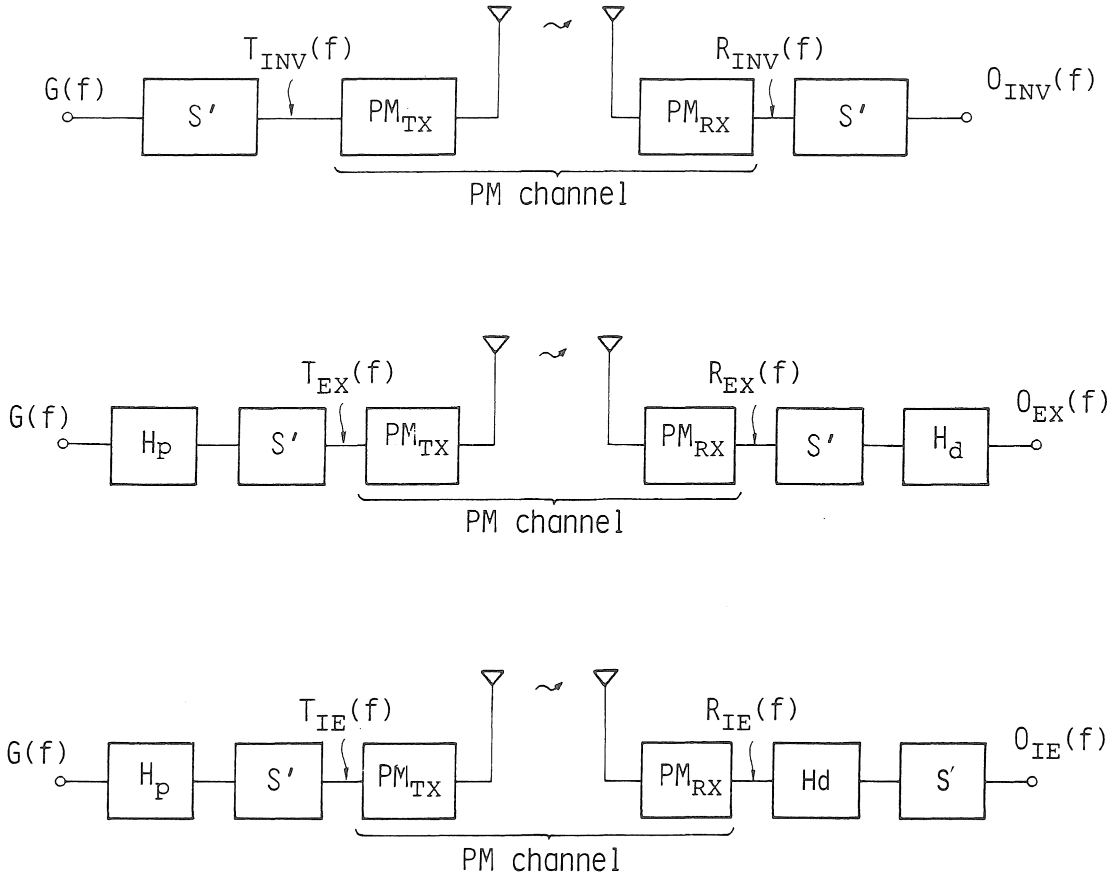

Fig. 4 Structural comparison of spectrum inversion PM transmission systems, (a) Spectrum inversion PM transmission system, (b) Spectrum inversion PM transmission system with existing emphasis, (c) Spectrum inversion PM transmission system with isomorphic emphasis.

$$Div'_{EX} = \int_{f_1}^{f_2} f^2 S'[Hp(f)G'(f)]df \tag{9}$$

Where Hp(f) is the square amplitude function of the existing pre-emphasis.

As the condition for matching the effective PM index Div'_{EX} given in Eq.9 with the non-encripted PM effective modulation for the phantom voice signal, previos studies have commomnly employed equal integrands directly in both Div'_{EX} and Div'_{PM} equations. That is

$$\begin{aligned} &G'(f) = Hp(fo-f)G'(fo-f) \quad or \\ &Hp(f) = G'(fo-f)/G'(f) \\ &\quad = \{1+f^2/fc^2\}/\{1+(fo-f)^2/fc^2\} \end{aligned} \tag{10}$$

Next effective PM index Div'_{EX} is found when existing pre-emphasis Hp(f) is used. When the existing emphasis shown in Eq.10 is substituted into Eq. 9, effective modulation Div'_{EX} immediately becomes

$$\begin{aligned} Div'_{EX} &= \int_{f_1}^{f_2} f^2\, Hp(fo-f)G'(fo-f)df \\ &= \int_{f_1}^{f_2} f^2[1+(fo-f)^2/fc^2]/[1+f^2/fc^2]\cdot \\ &\quad 1/[1+(fo-f)^2/fc^2]df \\ &= \int_{f_1}^{f_2} f^2/[1+f^2/fc^2]df = Div'_{PM} \end{aligned} \tag{11}$$

As seen in this equation, effective PM index Div'_{EX} does in fact match non-encripted effective PM index Div'_{PM} with regard to the specfied input signal G'(f) but modulation deviation agreement cannot be guarantied with regard to the arbitrary input signal G(f).

3.2 Effective PM Index in a Spectrum Inversion Transmission System using Isomorphic Emphasis

Effective PM index Div'_{IE} relative to the arbitrary input signal G(f) for a spectrum inversion transmission system using isomorphic emphasis, as shown in Fig.4 (c), is given as follows (From this point, arbitrary input G(f) and not specified phantom voice signal G'(f) is analysed as the input signal):

$$Div_{IE} = \int_{f_1}^{f_2} f^2 S'[H(f)G(f)]df = \int_{f_1}^{f_2} f^2 H(fo-f)G(fo-f)df \quad (12)$$

Here, H(f) is the square amplitude function of isomorphic emphasis.

It is necessary for Div_{IE} to match the below non-encrypted effective PM index Div_{PM}

$$Div_{PM} = \int_{f_1}^{f_2} f^2 G(f)df \quad (13)$$

The square amplitude function H(f) of isomorphic emphasis is not defined by equalizing the integrands in Eqs.12 and 13 directly, but rather by equalizing the integrations in the two equations. In other words, it must be found from the condition of effective PM index being equal. First, the variable on the right side of Eq.12 is changed as follows:

$$x = fo-f, \qquad dx = -df \quad (14)$$

Then, effective PM index Div_{IE} of isomorphic shown in Eq.12 is modified

$$Div_{IE} = \int_{f_2}^{f_1} (fo-x)^2 H(x)G(x)(-dx) \quad (12')$$

Changing the integral operand of Eq.12' and setting variable x to be f again, effective PM index Div_{IE} is finally given

$$Div_{IE} = \int_{f_1}^{f_2} (fo-f)^2 H(f)G(f)df \quad (15)$$

Here, isomorphic emphasis is first found from the condition of the integrands of eq.15 of Div_{IE} (Eq. 15) and non-encripted effective PM index Div_{PM} (Eq.13) being equal. That is

$$f^2 G(f) = (fo-f)^2 H(f)G(f)$$

Then, the square amplitude function H(f) of isomorphic emphasis is found

$$H(f) = f^2/(fo-f)^2 \quad (16)$$

That the modulation deviation of a spectrum inversion transmission system using the isomorphic emphasis found in Eq.16, in fact, matches non-encripted effective PM index is shown below.

Substituting isomorphic emphasis function Eq. 16 into Eq.12, we get

$$Div_{IE} = \int_{f_1}^{f_2} f^2 S'[H(f)G(f)]df = \int_{f_1}^{f_2} f^2\{(fo-f)^2/f^2\}G(fo-f)df = \int_{f_1}^{f_2} (fo-f)^2 G(fo-f)df \quad (17)$$

After changing the variable x to fo-f and replacing the variable x with f, it becomeç apparent that Eqs. 17 and 13 identically equate. That is,

$$Div_{IE} = \int_{f_2}^{f_1} x^2 G(x)(-dx) = \int_{f_1}^{f_2} f^2 G(f)df \equiv Div_{PM}, \quad QED. \quad (18)$$

As proven in this equation, regardless of whether or not spectrum inversion is applied, when isomorphic emphasis H(f) is employed, effective PM index Div_{IE} of the input signal G(f) always equates perfectly with non-enctipted effective PM index Div_{PM} of the arbitrary input signal.

4. STRUCTURE AND TRANSMISSION CHARACTERISTICS OF SPECTRUM INVERSION SYSTEMS USING EACH TYPE OF EMPHASIS

The importance of pre-emphasis in maintaining modulation deviation, that is in preventing transmission SNR degradation, was discussed in Section 2. Then, isomorphic emphasis for making effective PM index of the arbitrary input signal match non-encripted effective PM index was covered in Section 3. This section will stipulate the system composition for each type of pre-emphasis and will discuss their transmission chracteristics. Regardless of which kind of emphasis is used and whether or not spectrum inversion is applied, an undistorted transmission characteristics is the minimum requirement. For the convenience of discussion without loss of generality, the PM transmission channels shown in Figs.1 and 4 consisting of a phase modulator, free-space propagation path and a phase demodulator are assumed to be free from distortion and the output signal from the phase demodulator is assumed to be exactly equal to the input to the phase modulator.

4.1 Structure and Transmission Characteristics of Systems using Existing Emphasis

In order to compare it with the comparison of a transmission system using isomorphic emphasis, a transmission system using existing emphasis, like that in Fig.4 (b), is first examined briefly. The output signal $O_{EX}(f)$ of the existing emphasis transmission system is given

$$O_{EX}(f) = H_d(f) \cdot S'[R_{EX}(f)] \tag{19}$$

Where $H_d(f)$ is the square amplitude function of existing de-emphasis, and $R_{EX}(f)$ is the phase demodulated output signal of the existing emphasis transmission system shown in Fig.4 (b).

On the other hand, the input signal $T_{EX}(f)$ to the phase modulator is given

$$T_{EX}(f) = S'[H_p(f) \cdot G(f)] \tag{20}$$

Since the PM transmission channel is assumed to be free from distortion, output signal $O_{EX}(f)$ is given

$$\begin{aligned} O_{EX}(f) &= H_d(f) \cdot S'[T_{EX}(f)] \\ &= H_d(f) \cdot S'\{S'[H_p(f) \cdot G(f)]\} \\ &= H_d(f) \cdot H_p(f) \cdot G(f) \end{aligned} \tag{21}$$

Accordingly by making existing de-emphasis Hd(f) the inverse number of existing pre-emphasais Hp(f), the transmission characteristic of a spectrum inversion transmission system will become to be free from distortion. The amplitude function Hd(f) of de-emphasis in a existing emphasis transmission system is given

$$Hd(f) = 1/Hp(f) = [1+(fo-f)^2/fc^2]/[1+f^2/fc^2] \tag{22}$$

As seen in Eqs.10 and 22, Hp(f) and Hd(f) are mutually distinguished. This is due to a difference in the emphasis circuits on the sending and receiving sides of the existing emphsis transmission system and bespeaks the intricacy involved in manufacturing these circuits.

4.2 Spectrum Inversion Transmission System with Isomorphic Emphasis

Transmission systems using isomorphic emphasis are characterized by equal emphasis on the sending and receiving sides. First, it will be shown that such emphasis does, in fact, exist.

The output signal $O_{IE}(f)$ of the isomorphic emphasis transmission system shown in Fig.4 (c) is given

$$O_{IE}(f) = S'[H'(f)R_{IE}(f)] \tag{23}$$

Where H'(f) for convenience of discussion is the square amplitude function of de-emphasis in a isomorphic emphasis transmission systems, H'(f) is required to equate with H(f). $R_{IE}(f)$ is the phase demodulated output signal in the isomorphic emphasis transmission system shown in Fig.4 (c)

On the other hand, the input signal $T_{IE}(f)$ to the phase modulator given as

$$T_{IE}(f) = S'[H(f)G(f)] \tag{24}$$

$T_{IE}(f)$ matches demodulated output $R_{IE}(f)$, since the PM transmission channel has no distortion. Therefore, output signal $O_{IE}(f)$ is reduced to

$$\begin{aligned} O_{IE}(f) &= S'[H'(f)T_{IE}(f)] = S'\{H'(f)S'[H'(f)G(f)]\} \\ &= H'(fo-f)H(f)G(f) \end{aligned} \tag{25}$$

Distortion-free transmission is realized when the output signal $O_{IE}(f)$ of the equation equates identically with the arbitrary input signal G(f). That is

$$G(f) = H'(fo-f)H(f)G(f) \quad or \quad H'(fo-f) = 1/H(f)$$

By multipling the operator S' (*) on each side of the above equation, H' (f) is found to be

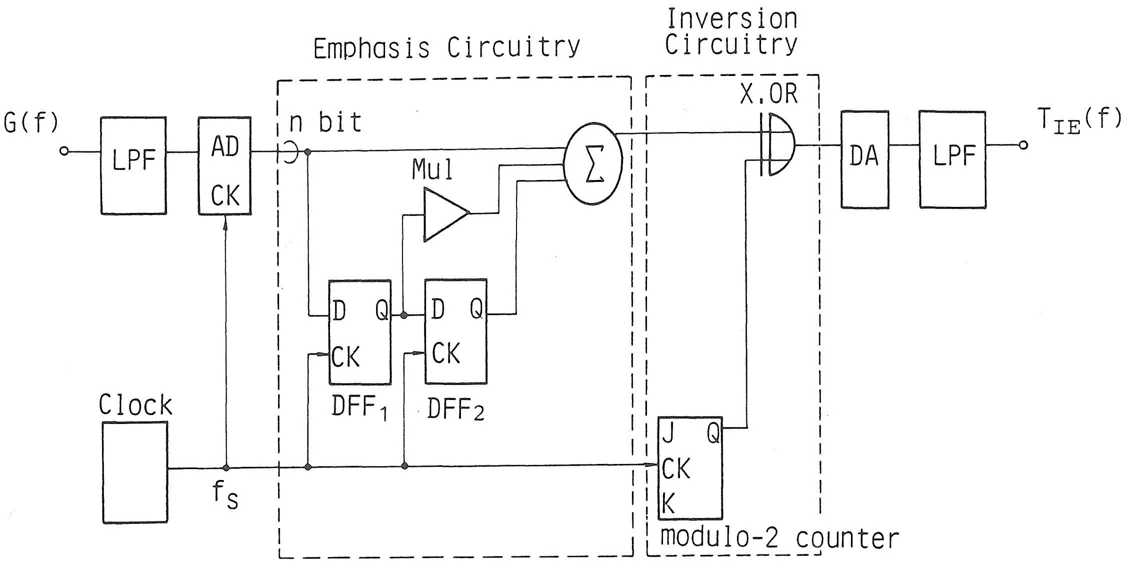

Fig. 5 An illustration of an isomorphic circuit

$$H'(f) = 1/H(fo-f) = f^2/(fo-f)^2 \equiv H(f) \qquad (26)$$

As seen in Eqs.16 and 26, H'(f) and H(f) match perfectly. This indicates that (1) even if spectrum inversion is employed, its effective PM index is the same as the non-encripted effective PM index, and (2) an isomorphic emphasis characterized by equal emphasis on the sending and receiving side in fact exist. Furthermore, because the sending and receiving circuits are the same, the repeatability of the circuits is improved, which gives superior cost performance when isomorphic emphasis is introduced into such existing transmission systems as mobile telephones and maritime telephones.

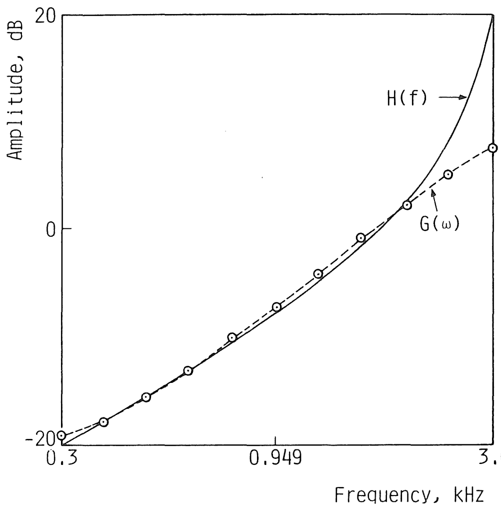

Fig. 6 Frequency response of optimized approximation $G(\omega)$

5. CIRCUITRY REALIZATION OF ISOMORPHIC EMPHASIS

As shown in Fig.4 (c), the speech processing circuits on both the sending and receiving sides of an isomorphic emphasis transmission system are provided with the same structure. As has been discussed in previous paper[6], a spectrum inversion circuit employing a digital signal processing with very simple structure and can theoretically provide undistorted processing easily. Therefore, as shown in Fig.5, it is considered that square amplitude function H(f) of isomorphic emphasis can be realized using a second order FIR DSP circuit. Therefore, isomorphic emphasis can be realized with a simple circuit, which has only DFF1 and DFF2 second order delay circuits (D-edge trigger flip-flops of n-bit resolution), a multipler with a 2α-coefficient and an adder with three input terminals as its circuitry elements. Such a circuit has the following system function H(z):

$$H(z^{-1}) = g(1-2\alpha\, z^{-1}+z^{-2}) \qquad (27)$$

Where z^{-1} is a variable of z-transformation, g is the amplitude constant and α is a parameter.

By substituting variable e^{-jw} into variable z^{-1} of eq.27, amplitude $G(\omega)$ and phase characteristic $\Phi(\omega)$ of the system function $H(z^{-1})$ given in Eq.27 can be respectively expressed

$$\begin{cases} G(\omega) = 2g(\cos\omega - \alpha) \\ \Phi(\omega) = -\omega \end{cases} \tag{28}$$

Here ω is the normarized angular frequency, $\omega = 2\pi f/fs$, and fs is the sampling frequency.

The optimum approximation is found next for minimizing the sum of the absolute value of the difference between the decibel value of the isomorphic emphasis function on the logarithm frequency axis and the decibel value of the system function. Namely, the evaluation function is expressed

$$\delta E = \int_{f_1}^{f_2} \left| \log G(\omega) - \log[f^2/(fo-f)^2] \right| d\log f \tag{29}$$

The optimum values of parameters α and g for minimizing Eq.29 are found as belows. For optimization, sampling frequency *fs* is set at *8kHz* and the input signal domain is set at [*0.3*～*3*] kHz; that is $f_1 = 0.3$kHz and $f_2 = 3.0$kHz. The broken line in Fig.6 shows frequency response based on optimum approximation where δE is minimized and when the values of parameters α and g are set at 1.0534 and 0.4480, respectively.

Though this figure, it can also be seen that, except for the neighborhood of the approximation domain edge f=3.0kHz deviation across almost the whole domain was within 0.6 dB, and that isomorphic emphasis with good approximation can be realized with a simple circuit. The reason for some degradation in the characteristic of the supremum neighborhood of the approximation domain is considered to be a high normalized angular frequency value of 0.75 π in that area, which approaches the effective limit of the digital signal processing filter. If the sampling frequency fs is set higher than 8kHz, a higher approximation accuray can be readily obtained; however, since this paper centers on discussing the possibility of realizing an isomorphic emphasis circuit, the subject of improving approximation accuracy will be taken up in another paper.

6. CONCLUSION

Isomorphic emphasis was proved as one method for adding a spectrum inversion function to radio communication systems while still avoiding degradation of speech quality. As long as the input signal is spectrum inverted directly, effective PM index of the spectrum inverted signal will increase by more than 12dB. In order to utilize finite frequency resources effectively, increasing the radio band during phase modulation must be avoided even when spectrum inversion is carried. To do this the strong input signal level in the conventional method must be attenuated by more than 12dB; however, this tends to degrade transmission SNR.

On the other hand, if the isomorphic emphasis discussed in this paper is adopted, effective PM index which is always equal to an arbitrary signal that has not undergone spectrum inversion will be obtained, even if the arbitrary signal is spectrum inverted. This means that transmission SNR will not degrade even if a spectrum inversion function is added to communication system. Furthermore, an equal sending and receiving emphasis characteristics means that repeatability in the manufacturing of the emphasis circuit can be increased and manufacturing costs reduced. At the same time, it also means that a pre-emphasis circuit for sending and a de-emphasis circuit for receiving can be used together in simplex (press to talk) communication system.

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