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Proposal of Isomorphic Emphasis in Spectrum Inversion of Analog PM Channel and Its Noise Reduction Effect

アナログ通信路を対象としたスペクトラム反転への送受同系エンファシスの提案と雑音抑圧効果

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ABSTRACT *In order to guard against infringement of confidentiality in mobile communication, the idea of adding an encryption function to radio communications has been studied from various approaches. Unfortunately, however, the existing methods have defect which the frequency occupancy bandwidth is enlarged by the increase of effective modulation index, or which complicated circuits is implemented in huge economical cost.*

With such a background in mind, this investigation establishes an appropriate circuitry realization method and economical optimum configuration for the new isomorphic emphasis. It has been given that isomorphic emphasis suppress the noise power well, even if a spectrum inversion encryption is introduced into PM transmission.

1. INTRODUCTION

With advances and diversification in the private and business sectors of society, the use of mobile communication systems is spreading at a quickening pace. Whereas these systems allow their users to place and receive calls whenever and wherever they desire, on the other hand, because these calls are carried via radio waves the danger of eavesdropping on them exists. In order to guard against infringement of confidentiality in such communication, an encryption function has become desirable [1].

Since the analog spectrum scrambler used in spectrum inversion provided strong speech security while, at the same time, possesses a standard interface with existing public telecommunication networks, there is high expectation for its practical application[2][3]. Unfortunately, however, the existing method which merely adds an encryption function generally raises effective emphasis above the level when no encryption is used (that is, non-encrypted PM transmission)[4]. Since this encrypted transmission is carried over the same radio frequency bandwidth as non-encrypted PM transmission, its input signal level must be reduced greatly.

With such a background in mind, the following sections will establish an appro

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3.1 Topology of Sending and Receiving PHUs

Figure 3(a) shows the primitive configuration of the sending PHU. So long as this previously reported circuitry realization method employing this primitive network topology is used, it becomes difficult to realize accurately the square amplitude function $H_i(f)$ though a simple circuit configuration.

Here, differing from the previously reported method[5] for realizing the circuit configuration shown in fig.3(a), a new circuitry realization method is introduced which is based on the isomorphic condition[6]. Presupposing the topology shown in fig.3(b), this method derives the canonical topology of circuit (b) from the condition that circuits (a) and (b) are equivalent; that is, it finds circuits H_a and H_b .

Making both $B_p(f)$ stand for the output signal of circuit(a), and $B_r(f)$ stand for the output signal of circuit(b), the instantaneous power characteristic when input signals have square amplitude $A(f)$ in both circuits is expressed

$$\begin{cases} B_p(f) = S[H_i(f)A(f)] \\ \qquad\; = H_i(f_0-f)A(f_0-f) \\ B_r(f) = H_b(f)S[H_a(f)A(f)] \\ \qquad\; = H_b(f)H_a(f_0-f)A(f_0-f) \end{cases} \tag{11}$$

If outputs $B_p(f)$ and $B_r(f)$ are equal, the two partial circuits will also be equivalent. Accordingly,

$$H_b(f)H_a(f_0-f) \equiv H_i(f_0-f) \quad \left(= (f_0-f)^2 f^{-2}\right) \tag{12}$$

Paying attention to the function formation in eq.12, it can be immediately shown that the following equation giving circuits $H_a(f)$ and $H_b(f)$ hold equal.

$$\begin{cases} H_a(f) = f^2 : & \textit{differential circuit} \\ H_b(f) = f^{-2} : & \textit{integral circuit} \end{cases} \tag{13}$$

When the canonical topology shown in fig.3(b) is employed, eq.13 signifies that isomorphic emphasis can be realized accurately with a cascaded architecture consisting of differential, spectrum inversion and integral function.

3.2 Circuit Configuration of IESIE Sending Side

The PM modulator can be realized as an equivalent of an FM modulator with a prepositioned differential circuit. Therefore, using this equivalent PM modulator, the IESIE sending side takes the configuration shown in fig.4(a). The shaded triangles in the figure indicate indispensable function blocks for the PM modulator and spectrum inversion circuit, and the blight triangles indicate additional function blocks for circuits added to realize transmission emphasis. The characteristics of the $H_b(f)$ integral circuit of transmission PHU and the prepositioned differential circuit of the PM modulator shown in fig.4 (a) can be respectively expressed f^2 and

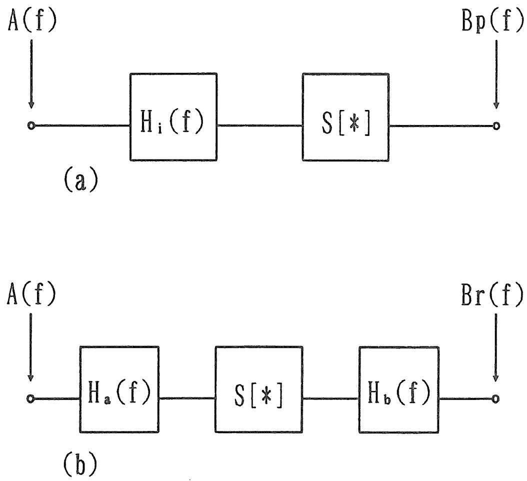

Fig.3 An illustrative cheme both of sending and receiving PHUs, (a) *primitive configuration topology,* (b) *canonical topology.*

in the IESIE system shown in fig.2(b) is given

$$Div_{IE} = \int_{f_1}^{f_2} f^2 S[H_i(f)G(f)]df \quad (3)$$

Here, $S[*]$ represents spectrum inversion, so, for example the operation for input signal $G(f)$ is expressed

$$S[G(f)] = G(f_0 - f) \quad (4)$$

Where f_0 stands for pivotal frequency of spectrum inversion and $f_0 = f_1 + f_2$, f_1 , f_2 for the infimum and supremum ends of the frequency band. Carrying out operation spectrum inversion $S[*]$ on Div_{IE} and substituting $H_i(f)$ given in eq.1 into it, the following is obtained:

$$\begin{aligned} Div_{IE} &= \int_{f_1}^{f_2} f^2 H_i(f_0 - f)G(f_0 - f)df \\ &= \int_{f_1}^{f_2} f^2\left\{(f_0 - f)^2 f^{-2}\right\}G(f_0 - f)df \end{aligned} \quad (5)$$

Changing the variable in the above equation as $x = f_0 - f$, $dx = -df$, we get

$$Div_{IE} = \int_{f_2}^{f_1} (f_0 - x)^2\left\{x^2(f_0 - x)^{-2}\right\}G(x)(-dx) \quad (6)$$

Changing the integral operand and setting variable x to f again, the final equation is obtained:

$$Div_{IE} = \int_{f_1}^{f_2} f^2 G(f)df \equiv Div_{PM}, \qquad QED. \quad (7)$$

Equation 7 signifies that when isomorphic emphasis is applied to the IESIE system, effective modulation index Div_{IE} will be identically equal to effective PM index Div_{PM} , irrespective of whether or not spectrum inversion has been applied to the arbitrary input signal.

2.2 Distortion - free Transmission Quality with Isomorphic Emphasis

As the first precondition, it must be shown that the IESIE system is distortion - free. If the IESIE system adopts the configuration shown in fig.1, then its output signal $O(f)$ in respect to arbitrary input signal $G(f)$ will be given

$$O(f) = S^{-1}[H_i(f)R(f)] = S[H_i(f)R(f)] \quad (8)$$

Here, $R(f)$ is the PM modulation output in the IESIE system and $S^{-1}[*]$ is the inverse mapping of spectrum inversion, which denotes $S[*]$ itself.

Now, making the input signal to be $G(f)$ and PM demodulated output signal to be $R(f)$ input signal$T(f)$ to be PM modulator and output signal $O(f)$ from the IESIE system are respectively given

$$\begin{cases} T(f) = S[H_i(f)G(f)] \\ O(f) = S[H_i(f)R(f)] \end{cases} \quad (9)$$

For convenience of discussion without loss of generality, the PM transmitter (PM_{TX}) in fig.2, consisting of a PM modulator, can be assumed to be distortion - free. Given this assumption,input signal $T(f)$ to the PM modulator and output signal $R(f)$ from demodulator established the relation $T(f) = R(f)$ Accordingly, output signal$O(f)$ is given as

$$\begin{aligned} O(f) &= S\{H_i(f)S[H_i(f)G(f)]\} \\ &= H_i(f_0 - f)H_i(f)G(f) \\ &= (f_0 - f)^2 f^{-2} \cdot f^2(f_0 - f)^{-2} \cdot G(f) \\ &\equiv G(f), \qquad QED. \end{aligned} \quad (10)$$

This equation signifies that the output and input signals are equal and shows the IESIE system to be distortion - free.

3. CIRCUITRY REALIZATION OF IESIE SYSTEM

priate circuitry realization method and economical optimum configuration for the previously reported new isomorphic emphasis which doesn't increase effective modulation, and will qualitatively discuss the noise reduction effect of that emphasis.

2. OUTLINE OF ISOMORPHIC EMPHASIS

The spectrum inversion transmission system using isomorphic emphasis is called the IESIE system, which is shortened for the Isomorphic Emphasis Spectrum Inversion Encryption transmission system and its configuration is shown in fig.1. As this figure shows, the main characteristic of the IESIE configuration is equal voice processing circuits on both the sending and receiving sides. These circuits will hereafter be called sending and receiving PHUs, which is short for Processing Half Unit. Since this transmission system employs the new isomorphic emphasis, it must satisfy the following preconditions:

(1) Irrective of the input signal and whether spectrum inversion is performed or not, effective modulation must always be the same as effective PM index of an input signal that has not been spectrum inverted. (The latter modulation is hereafter called non-encrypted PM modulation.)

(2) If the PM transmission path is distortion free, the transmission system must also be the same.

(3) The sending and receiving PHUs must take the same form.

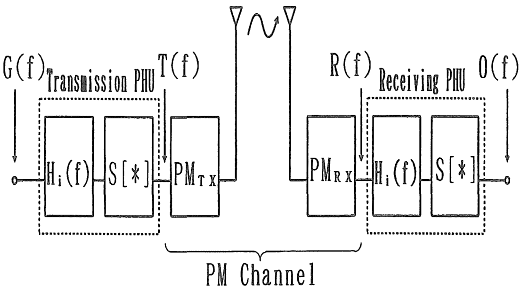

Fig.1 Configuration of Isomorphic Emphasis Spectrum Inversion (IESIE) System.

2.1 Modulation Maintainability with Isomorphic Emphasis

Let's prove that the effective modulation index Div_{IE} of the arbitrary input signal (whose square amplitude function is noted $G(f)$) is equal to the non-encrypted effective PM index Div_{PM} under the assumption that the square amplitude function $H_i(f)$ of isomorphic emphasis is given

$$H_i(f) = f^2/(f_0 - f)^2 \tag{1}$$

Now, when the non-encrypted PM transmission system has the configuration shown in fig.2(a), its effective modulation index Div_{PM} is given as follows:

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

On the other hand, effective modulation

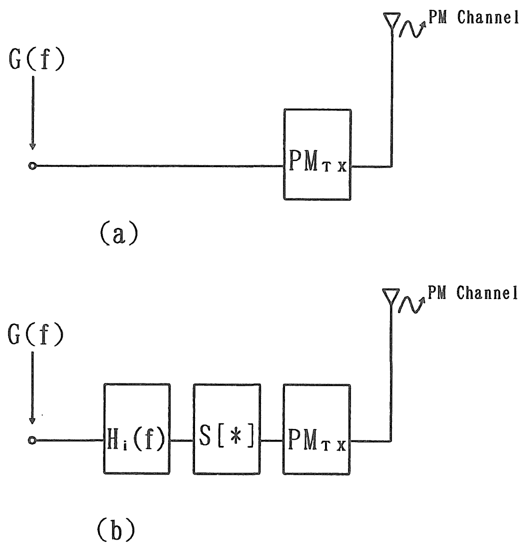

Fig.2 Circuitry configuration of sending side, (a) non-encrypted PM transmission system, (b) encrypted transmission system with Isomorphic Emphasis (IESIE System).

f^{-2} if circuit realization is ideal, so they cancel each other out. As a result, the circuit configuration of the IESIE transmission system is obtained as shown in fig.4 (b).

3.3 Configuration of IESIE Receiving Side

Since equality of the sending and receiving PHUs are the third precondition of isomorphic emphasis, naturally topology must match. Accordingly, the primitive IESIE receiving side adopts the configuration shown in fig.5(a).

As in fig.4, shaded triangles mark the indispensable function blocks of the PM demodulator and spectrum inversion circuit and bright triangles mark additional function blocks for realizing isomorphic emphasis in fig.5 as well. Ideally, the differential circuit which is the partial circuit $H_a(f)$ in the receiving PHU of fig.5(a) and the integral circuit which is the postpositioned circuit in the equivalent PM modulator should cancel each other out, resulting in the transmission system configuration shown in fig.5(b).

As just mentioned, isomorphic emphasis provides a transmission system through a configuration that does not require any additional circuit, which makes the cost benefit in applying it to spectrum inversion easy to see. As an example, it is seen that the two transmission systems in fig.6(a) an existing spectrum inversion transmission system without any emphasis and (b) a spectrum inversion transmission system employing isomorphic emphasis have the same structural elements, but in opposite order.

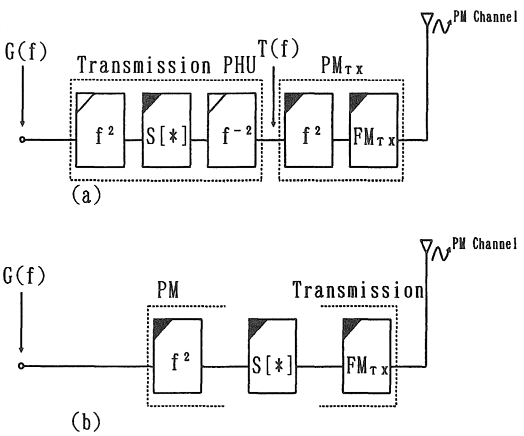

Fig.4 Detailed circuitry configuration of sending side, (a) *non-encrypted PM transmission topology,* (b) *IESIE System.*

4. QUALITATIVE EXAMINATION OF THE NOISE REDUCTION EFFECT

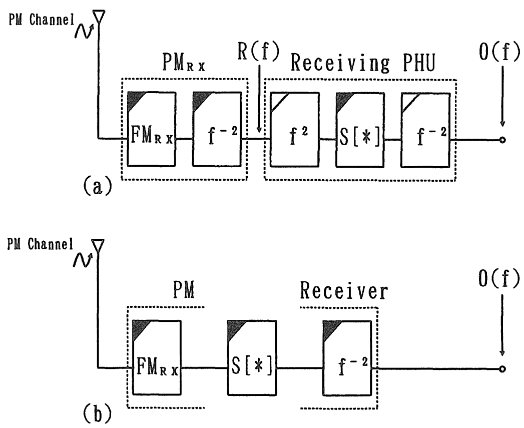

Fig.5 Circuitry configuration of receiving side, (a) *non-encrypted PM transmission topology,* (b) *IESIE System.*

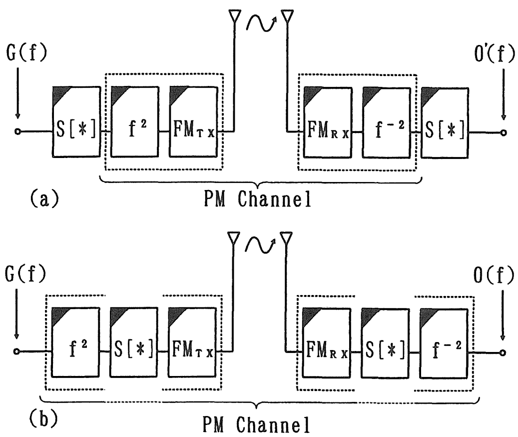

Fig.6 Comparison of transmission system for speech encryption, (a) *existing spectrum inversion without emphasis,* (b) *new system with IESIE.*

A long-term average of receiving noise power in NTT's current mobile telephone system is shown in fig.7, which given relation between receiving electric field strength in the center and at the border of the service area[5]. As is commonly known, many mobile telephone systems employ PM modulation, and as is shown in this figure, for the most part noise power exhibits an f^{-2} characteristic irrespective of the receiving electric field strength. This means that the dominant receiving noise factor is fading noise[7].

The cause of fading noise in mobile communications is phase fluctuation that occurs when the vehicle is moving within quasi standing-wave field, and it takes the form of clicking produced FM demodulation. Therefore, fading noise contained in the FM demodulated output signal exhibits a white noise characteristic, whereas that in the PM demodulated signal exhibits an f^{-2} characteristic. Naturally, fading noise is not present in the frequency characteristics of the output signal of a transmission system.

As is shown in fig.5, the receiving side of the IESIE transmission system devides equivalently FM demodulated output signals, spectrum inverts them, and lastly integrates them. The long-term average of fading contained in the input signal of spectrum inversion exhibits a white characteristic within the frequency band. Even if white noise is spectrum inverted, its frequency characteristic will still remain white. Therefore, it is easy to conjecture that the frequency of noise contained in the output signal of a transmission system which is able to integrate a spectrum inverted output signal would have an f^{-2} characteristic.

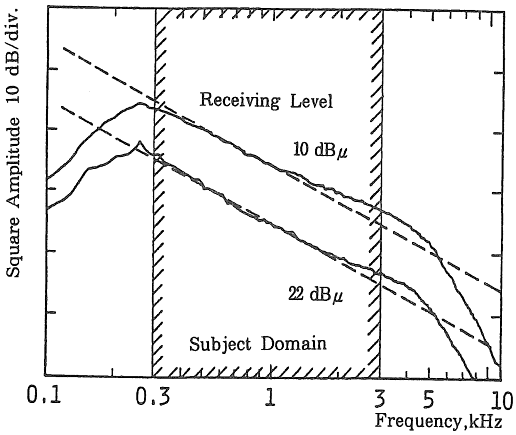

Fig.7 A long-term average of receiving noise power in PM current mobile telecommunication system.

Conventionally, the PM transmission system has been considered ideal for voice transmission. This is because the long-term average of its voice power and the long-term average of fading noise power, which is its dominant receiving noise, both exhibits predominately f^{-2} characteristics as shown in fig.8[8]. That is, the PM transmission system is generally thought of as ideal because its provides good voice quality by maintaining a uniform ratio between the signal and noise components within its transmission band, as long as the noise component of each of its frequencies dose not exceed its signal component, the signal component will audiogramly mask the noise component.

Due to the fact that the IESIE transmission system has nearly the same voice

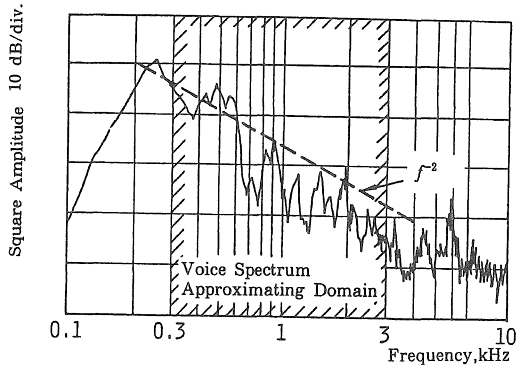

Fig.8 A long-term average of typical human voice.

power characteristic as the PM transmission system it assures excellent communication quality.

5. CONCLUSION

Placing emphasis on improving the structual simplicity and economy of the realized circuits, a circuitry realization method for new isomorphic emphasis has been discussed along with its noise reduction effect.

Being based on the isomorphic emphasis, perfectly symmetrical **Signal Processing Half Units**(PHUs) were provided on the sending and receiving sides, which enhances PHU repeatability. Furthermore, when these PHU are applied in a PM transmission system using an equivalent PM modulator or in a PM receiving system using an equivalent PM demodulator, no additional circuits are required to realize isomorphic emphasis.

A look has also been taken at fading noise which is the dominant noise factor in mobile telephones, and it has been seen that the long-term average of the noise power contained in the output signal of a receiving system employing isomorphic emphasis is in line with the power spectrum of fading noise in a non-encrypted transmission system, which in qualitative terms means that the IESIE transmission system provides communication quality similar to that of the existing mobile telephone system without any encryption.

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