United States Patent [19]

Miller

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[54] **VOICE PRIVACY DEVICE**

[75] Inventor: **Charles K. Miller**, Concord, Mass.

[73] Assignee: **Technical Communications Corporation**, Lexington, Mass.

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[52] **U.S. Cl.** ....**325/32**, 179/1.5 R, 179/1.5 S

[51] **Int. Cl.** **H04k 1/04**

[58] **Field of Search**.....325/32, 132; 179/1.5 S, 1.5 R

[56] **References Cited**

UNITED STATES PATENTS

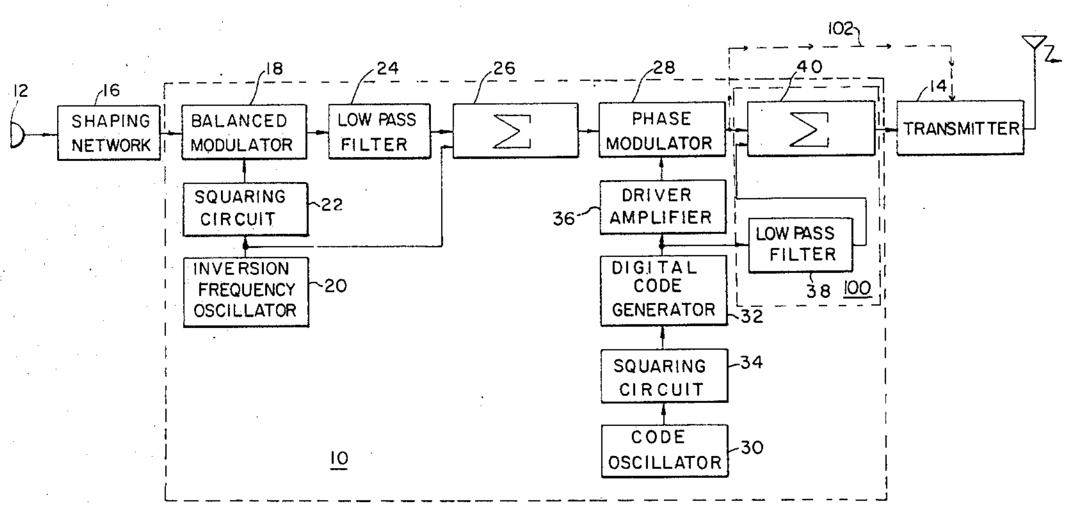
2,479,338	8/1949	Gabrilovitch	179/1.5
2,905,747	9/1959	Kidd et al.	178/5.1
3,610,828	10/1971	Girard et al.	179/1.5
3,180,927	4/1965	Heppe et al.	179/1.5
3,341,659	9/1967	Stern	179/1.5

Primary Examiner—Benjamin A. Borchelt
Assistant Examiner—H. A. Birmiel
Attorney—Cesari and McKenna

[57] **ABSTRACT**

A voice privacy coder system enables transmission of voice communication in privacy by first inverting the communication and then scrambling it directly with a complex code word. In one embodiment, a tone at the inversion frequency is also scrambled in with the voice communication and the complex code is added to the scrambled signal prior to transmission to provide synchronizing signals for the receiver; a decoder at the receiver reconstitutes the scrambled communication. In an alternate embodiment, the complex code is omitted from the transmitted signal and the inversion tone and code are reconstituted at the receiver by means of cross-coupled phase-lock and synchronizing loops.

26 Claims, 2 Drawing Figures



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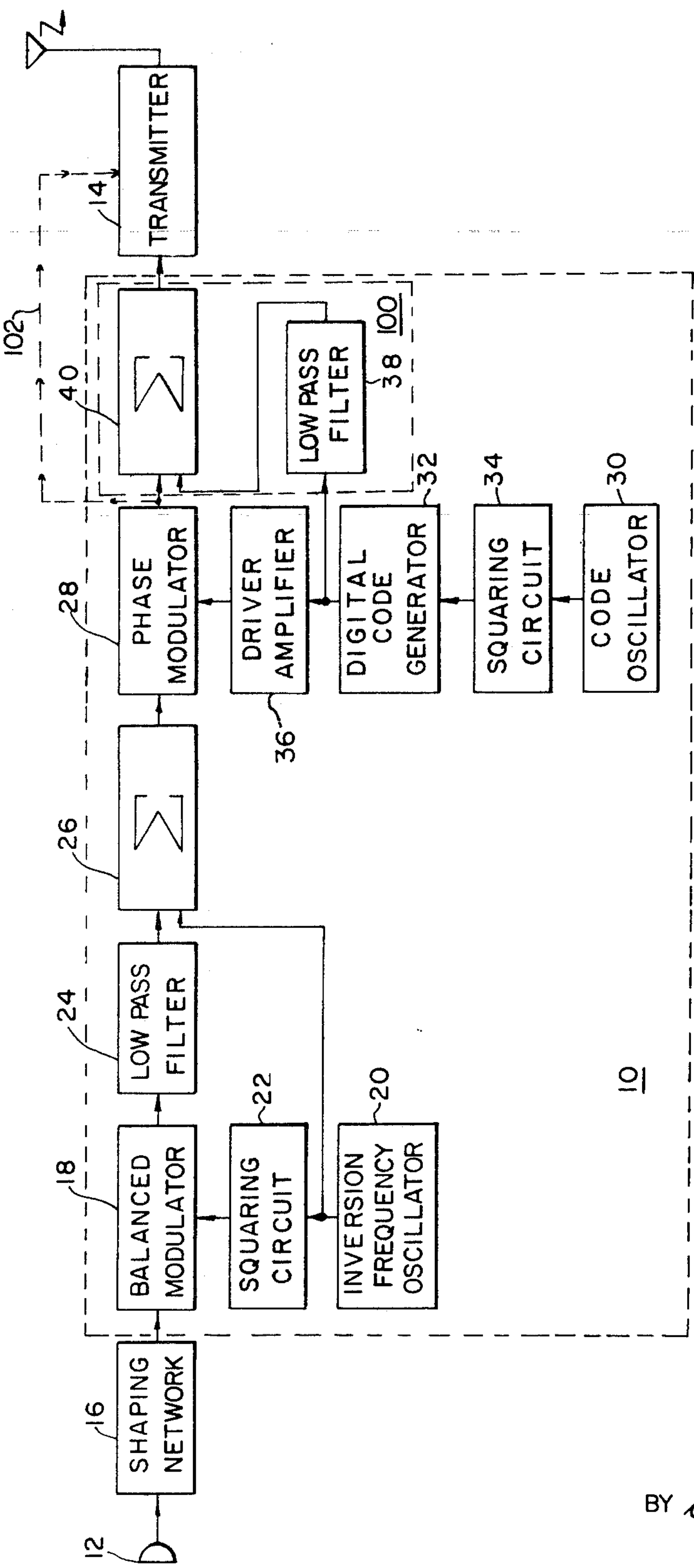

FIG. I

INVENTOR
CHARLES K. MILLER
BY Cesari & McKenna
ATTORNEYS

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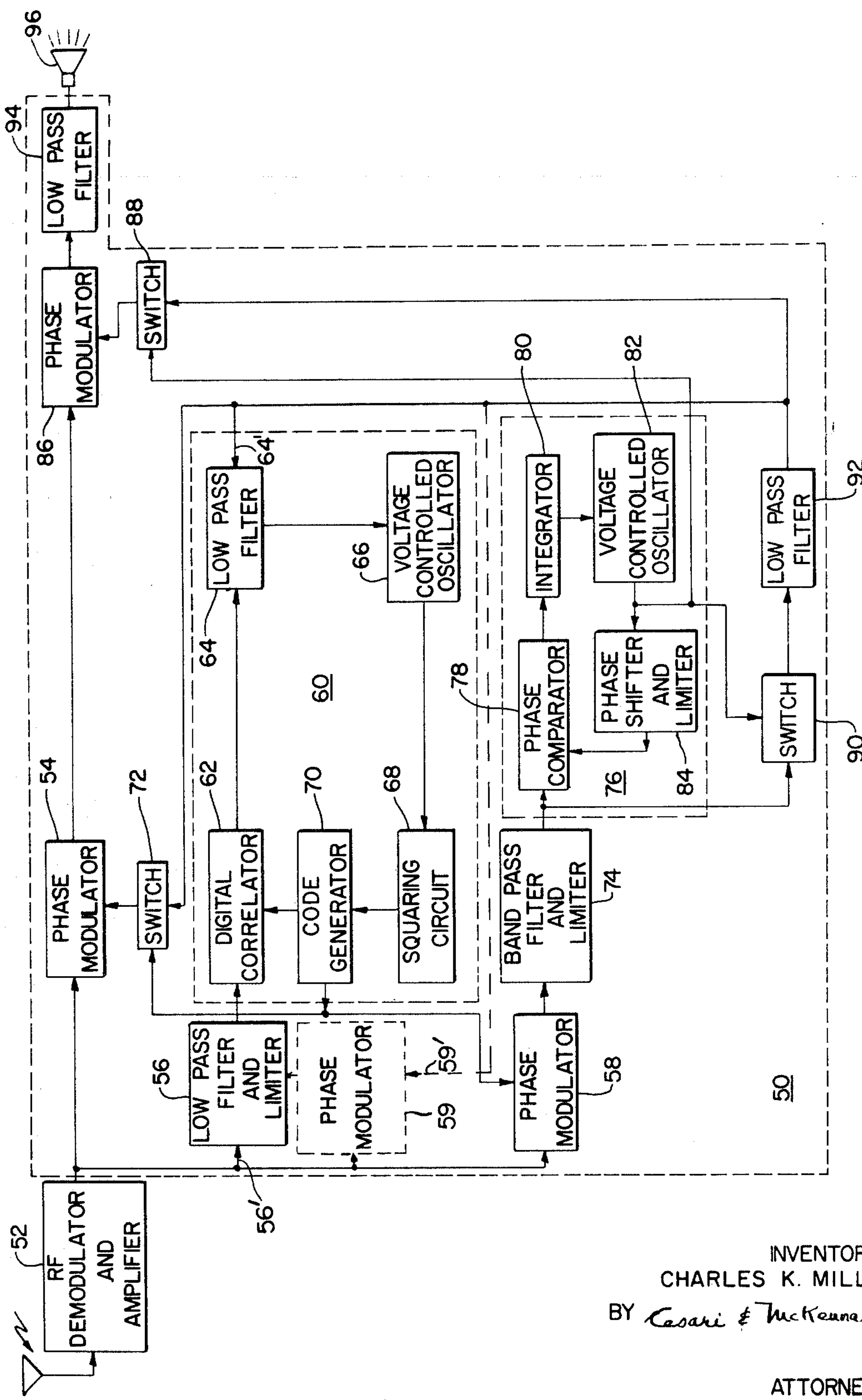

FIG. 2

INVENTOR
CHARLES K. MILLER
BY Casari & McKenna
ATTORNEYS

VOICE PRIVACY DEVICE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention comprises a voice privacy coder system and, more particularly, a voice coder system requiring a very narrow bandwidth for transmission of secure communications. This application is a continuation-in-part of my earlier filed application, Ser. No. 23,754, entitled "Voice Privacy Device" filed Mar. 30, 1970 and assigned to the assignee of the present invention.

2. Prior Art

A voice privacy coder system scrambles voice communications prior to their transmission over an exposed transmission link. This scrambling may be accomplished in many different ways.

In one form of scrambling heretofore proposed, the communication which is to be privately transmitted is modulated at a number of different frequencies which are harmonically related to one another, and one of the sidebands at each of these frequencies is then transmitted. This system, while simple and easy to implement, achieves only a moderate degree of privacy since the fundamental frequency and its harmonics are readily detected and the transmitted signal therefore readily unscrambled.

Another system which has been proposed quantizes the analog signal to be transmitted so as to form a binary coded pulse train which represents the magnitude of the analog signal at various points of time. Certain of the digits in this pulse train are then set equal to their complementary values (0 or 1, as the case may be) in accordance with a selected code which is regenerated at the receiver for unscrambling the coded signal. This system provides a high degree of privacy but is rather complex and, therefore, difficult to implement. Further it requires a large bandwidth for effective reproduction of the communication at the receiver.

A private communication system capable of reproducing voice communications in the low audio range (0 to 3 kHz) and having very narrow bandwidth requirements is described in the copending application of Alfred L. Girard et al., Ser. No. 640,665 filed May 23, 1967 and assigned to the same assignee as the present invention. The system described in that application scrambles a voice communication with a complex code word. It is suggested in that application that the "security" of the communication (i.e., the difficulty with which the communication may be recovered from the scrambled signal by unauthorized interceptors of it) may be increased by inverting the signal after it has been scrambled and prior to transmission. Such a system is capable of providing greater security with still acceptable fidelity. However, scrambling the voice communication prior to inversion generates a large number of modulation products which, if not filtered prior to inversion, may interfere with each other during descrambling, thus degrading to some extent the quality of the signal.

Other systems have been proposed in which a voice communication to be transmitted in privacy is first single-sideband modulated onto a constant frequency carrier and is then scrambled with a second signal whose frequency is varied in accordance with a code word. An example of one such system is described in an article by

L.E. Zegers appearing in Vol. COM-16, No. 6 of the IEE Transactions on Communication Theory, Dec., 1968. Such a system requires a very stable local oscillator in the receiver to generate the demodulating signal for the single sideband transmission and, additionally, requires a highly stable very linear, controlled oscillator in the receiver to generate the appropriate descrambling signal in accordance with the locally-regenerated code word. These oscillators greatly increase the cost of such a system. Further, because phase synchronization cannot be maintained, the quality of the decoded signal is degraded.

SUMMARY OF THE INVENTION

A. Objects of the Invention

Accordingly, it is an object of the invention to provide an improved voice privacy coder system.

Further, it is an object of the invention to provide an improved voice privacy coder system which has only narrow bandwidth requirements.

Another object of the invention is to provide an improved voice privacy coder system in which the privacy of the communication is enhanced in comparison with other systems without significant additional complexity or degradation of the fidelity and without the need for expensive, highly-stable oscillators.

A further object of the invention is to provide an improved voice privacy coder system which is readily adapted to existing non-private communication systems.

Still another object of the invention is to provide an improved voice privacy coder system in which a synchronizing signal for reconstruction of the code is buried within the coded communication itself and is transmitted with the coded communication in a common frequency band.

Yet another object of the invention is to provide an improved voice privacy coder system in which the synchronizing signal to be transmitted with the coded communication is itself scrambled prior to its transmission.

B. Brief Description of the Invention

In accordance with the foregoing objects, the voice communication which is to be transmitted in privacy is processed in a coder connected to the voice source. The coder first inverts the communication, then scrambles it with a complex code word. The inversion is performed by first phase modulating the communication with a single pure tone (the "inversion tone") and subsequently filtering out the upper sideband modulation product. The resultant signal consists of a lower sideband only, having the characteristic that the frequency components of this signal are inverted, that is, the low-frequency components of the voice signal are translated to the high-frequency end of the modulated signal and the high-frequency components of the voice signal are translated to the low frequency end of the modulated signal. The scrambling is achieved by phase modulating the inverted signal directly with the complex code word.

To establish synchronizing signals at the receiver and thereby obviate the use of highly stable local oscillators, the inversion frequency and the complex code itself are transmitted with the voice communication. The complex code is transmitted to the receiver directly by adding it at a low level to the scrambled signal prior to transmission, while the inversion frequency tone is preferably added to the inverted voice communication prior to its scrambling so that it is scrambled with the complex code word along with the inverted voice communication. This enhances the privacy of the communication system.

At the receiver, the complex code word is recovered from the received signal by means of a code synchronization loop which performs a correlation operation on the received signal to regenerate the code. The regenerated code is then used to descramble the signal. The inversion frequency tone is recovered from the descrambled signal by means of a phase lock loop which locks a local oscillator to the inversion frequency. The voice communication is then recovered by re-inverting about the inversion frequency.

In an alternative embodiment, the complex code word is omitted from the transmission and the sole synchronizing signal comprises the inversion tone which is added to the inverted voice communication prior to scrambling. The resultant transmitted signal then has two components, namely, the inverted scrambled voice communication and the scrambled inversion tone which serves as the synchronizing signal.

The complex code word and the inversion tone are recovered from the received synchronization signal at the receiver by means of a code synchronization loop and a phase lock loop which are cross coupled to each other. The input to each loop is through a phase modulator having the synchronization signal applied as a first input and having the output of the opposite loop as a second input; the output of each loop is then the complex code word and the inversion tone, respectively. These are used to descramble the received communication and to then reinvert it to recover the original voice communication.

DETAILED DESCRIPTION OF THE INVENTION

The foregoing and other and further objects and features of the invention will be understood more clearly on reference to the following detailed description of the invention when taken in conjunction with the accompanying drawings in which:

FIG. 1 is a schematic diagram of a portion of a radio transmitter connected to the encoder of the present invention for scrambling a communication prior to transmission; and

FIG. 2 is a schematic diagram of a portion of a radio receiver connected to the decoder of the present invention for unscrambling the received communication.

In FIG. 1, the encoding apparatus **10** of the present invention is interposed between an analog signal source **12** (illustratively shown as a microphone) and a transmitter **14** (which may include radio frequency modulating and amplifying stages). The encoding apparatus **10** includes a wave-shaping network **16** for filtering out signal components from the microphone **12** which may lie outside the bandwidth of the signal to be transmitted. For example, when speech is to be transmitted, the network **16** may include filter elements which attenuate at frequencies below 300 Hz and above 3 kHz, which is thus the bandwidth to which the coder must be accommodated.

After the passage through the network **16**, the voice signal is applied to a phase modulator **18** where it is modulated with a carrier supplied to the modulator from an oscillator **20** through a squaring circuit **22**. The oscillator **20** generates a sinusoidal output at a single frequency called the "inversion" frequency; this output is converted by the squaring circuit to a signal which is substantially a square wave and which drives the modulator **18** on and off at precisely defined times. The modulator **18** may advantageously be formed from a pair of transistor switches arranged in a balanced configuration and followed by a difference amplifier having its inputs connected to the respective switch outputs. In the time domain, the output of the modulator is an analog of the audio signal in which successive segments are shifted by **180°** in accordance with the applied carrier. In the frequency domain, the output of the modulator **18** comprises upper and lower sidebands centered around the fundamental frequency of the oscillator **20** and its higher harmonics as contained in the square wave. For voice communications in a 300 Hz – 3 kHz passband, the inversion frequency is selected to be within the passband, e.g. at 2.7 kHz.

The modulator output is applied to a low pass filter **24** which filters out the upper sideband positioned above the fundamental inversion frequency, together with all other modulation products centered around higher frequencies. The output of the filter **24** thus comprises a single lower sideband below the fundamental inversion frequency; this sideband is hereafter referred to as the "inverted voice communication."

The inverted voice communication is added to a portion of the output of the oscillator **20** in a summer **26** and this sum is then applied to a phase modulator **28** having a construction similar to that of the modulator **18**. An oscillator **30** drives a digital code generator **32** through a squaring circuit **34** which converts the sinusoidal output of the oscillator **30** to a uniform square wave; the oscillator may advantageously operate at a frequency of 1 kHz. The code generator **32** in turn drives the balanced modulator **28** through a driver amplifier **36**; it generates a complex digital code which is used to phase modulate the output of the summer **26**. Although various forms of digital code generators may be used, the generator **32** may advantageously comprise a digital shift register having one or more feedback connections around portions of the register to repetitively generate a complex code word which is pseudo random in nature, that is, the distribution of "1"s and "0"s in the word is nearly that of a random distribution. The generator **32** is set to an initial state by the operator. This state defines a particular code "word" which is applied to the modulator **28** bit by bit at a rate determined by the oscillator **30**. The word is then continuously repeated during the transmission. The inverted voice signal, to which the inversion frequency tone has been added, is scrambled directly with this code word, by means of the modulator **28**, to provide a signal which is unintelligible to those not having the proper equipment to reconstitute the voice communication. The code word may be varied by changing the feedback connections around the shift register.

The output of the code generator **32** is filtered in a low-pass filter **38** and is then added to the scrambled output of the modulator **28** in a summer **40**. The filter **38** removes the high frequency components of the code word prior to transmission to minimize interference with the recovered audio signal on subsequent decoding; the filtered code serves as a second synchronizing signal for recovery of the scrambled voice communication as will be seen below. To make detection more difficult, the signal level of the code should preferably be of the order of 10 percent of the signal level of the scrambled communication.

The output of the summer **40** thus comprises a scrambled inverted version of the voice communication to which the complex code has been added at a low level. This composite signal is applied to the transmitter **14** for transmission to a remote receiver. The transmitter **14** performs appropriate wave-shaping and frequency translating operations on the scrambled signal prior to its transmission to the remote receiver. For example, when the encoding apparatus is used in a mobile two-way radio communication system, the scrambled signal will be radio-frequency modulated onto a carrier signal whose frequency is of the order of 100 mHz or more. In such a case, the scrambled signal will occupy only a very small bandwidth centered at the frequency of the carrier. When the transmission link is to comprise a telephone transmission line, on the other hand, the transmitter **14** need not necessarily contain frequency translating circuitry; indeed the transmitter may be eliminated altogether. The reason for enclosing the filter **38** and summer **40** in a rectangular box and for showing a dotted line bypass around the summer **40** and between the modulator **28** and the transmitter **14** will be made more clear below in connection with a discussion of an alternative embodiment of the transmitter of FIG. **1**. For the present, these modifications may be ignored.

In FIG. **2**, decoding apparatus **50** is shown embodied in a radio receiver. The receiver incorporates a radio frequency demodulator and amplifier **52** for recovering the scrambled communication from the carrier frequency onto which it has been superimposed. The scrambled communication is then applied to a phase modulator **54**, a low-pass filter and limiter **56**, and a phase modulator **58**. The presence of a phase modulator **59** may be ignored for the moment.

The filter and limiter **56** has a 3 db cutoff at approximately the frequency of the code word so that the signal components at higher frequencies are rejected by it. The output of the filter **56** is applied to a code synchronization loop **60** comprising a digital correlator **62**, a low-pass filter **64** which may include an active amplifying element, a voltage controlled oscillator **66**, a squaring circuit **68** and a code generator **70**. The correlator **62** receives inputs from the filter **56** and the generator **70**. The generator **70** in turn is driven from the oscillator **66** through the squaring circuit **68**. The output of the correlator **62** is applied through the filter **64** as a control input to the oscillator **66**.

The code generator **70** may advantageously comprise a digital shift register similar to the register **28** in the transmitter and initially set to the same code word. The contents of the register are shifted bit by bit in response to driving signals from the oscillator **66** until the corresponding bits in the transmitter code generator and receiver code generator are "aligned" or "synchronized". The frequency of the oscillator **66** is controlled by the output of the correlator **62** which, in turn, is dependent on the output of both the code generator **70** and the filter and limiter **56**. The correlator **62** may simply comprise a pair of AND gates driving the positive and negative inputs, respectively, of a difference amplifier connected in an integrating configuration.

The code synchronization loop **60** extracts the low level complex code from the scrambled signal for subsequent use in descrambling the signal. It does this by correlating the received signal with the locally generated complex code word and then advancing or delaying the shifting of bits in the shift register of generator **70** until the generated code is synchronized with the received code. When the code generated by the generator **70** is in phase with the code contained in the scrambled signal, the gates in the correlator alternately drive the positive and negative inputs of the integrating amplifier; these driving signals are integrated to provide a zero net contribution to the amplifier output over the integrating period. As long as the output of the code generator **70** is in phase with the code contained in the scrambled signal, therefore, the amplifier output remains constant and the oscillator **66** supplies a constant frequency output.

If now, the output of the generator **70** is out of phase with the code word in the scrambled signal, one of the correlator gates will be opened for a greater length of time that the other of the gates, the particular gate being dependent on the direction of the phase displacement between the code word in the scrambled signal and the code generated by the generator **70**. The uneven opening of the gates drives the integrating amplifier in one direction or the other to provide a net (non-zero) output which causes the voltage controlled oscillator **66** to change its instantaneous frequency in one direction or the other in accordance with the phase displacement between the two signals; this drives the generator **70** in a direction such as to minimize this phase displacement. Thus, the generator **70** is locked onto the code word in the scrambled signal to reproduce the code word at the receiver.

To obtain a shorter synchronization time for the complex code word, it is desirable to operate the oscillator **66** at a slightly higher rate than the bit rate of the code word itself during the acquisition cycle and then switch to the synchronous rate once the code word has been acquired. This frequency offset is readily obtained by introducing a bias voltage into the active amplifying element of filter **64** during the time the code word is being acquired so as to operate the oscillator at a frequency above the synchronous frequency and then removing this bias after synchronization has been achieved. The bias switching is advantageously performed in response to a switching signal applied to the amplifying element over a lead **64'** from an acquisition detection circuit described in more detail below. Thus, prior to synchronization, the bias offset of this element is set such as to drive the oscillator **66** to a frequency of the order of 50–100 Hz above the bit rate of the code word. When synchronization is achieved, the offset is removed so as to drive the oscillator to a frequency corresponding to the synchronous frequency, that is, a frequency equal to the bit rate of the code word.

Simultaneous with the switching of the bias voltage for the frequency offset, the noise bandwidth of the loop should be changed from a high value during acquisition of the code to a lower value after synchronization has been obtained. The increased bandwidth during acquisition assists in ensuring rapid synchronization but would degrade signal quality after synchronization if not reduced at that time. The change in bandwidth is readily accomplished by changing the gain of the active amplifying element after synchronization is achieved and is preferably done in response to the same switching signal as is utilized for switching the bias voltage for the frequency offset.

The output of the generator **70** is applied to the modulator **58** and also to a switch **72** associated with the modulator **54**. The scrambled, inverted communication at the output of the modulator **52** is unscrambled in the modulator **58** by remodulating it with the complex code word regenerated in the generator **70** of code synchronization loop **60**. The descrambled output, which comprises the inversion tone plus the inverted voice communication is applied to a band pass filter and limiter **74** having a center frequency at the inversion frequency.

The filter **74** passes only the pure tone at the inversion frequency and this is applied to a phase lock loop **76** comprising a phase comparator **78**, an integrator **80**, a voltage controlled oscillator **82**, and a phase shifter and limiter **84** connected in a closed loop. The comparator **78** compares the phase of the recovered inversion tone with respect to the phase of the oscillator **82**. If the two signals are out of phase, the comparator **78** provides an output which, when integrated by the integrator **80**, provides a driving signal to the oscillator **82** to shift its frequency in one direction or the other to minimize the phase difference. The phase shifter and limiter **84** provides a 90° phase shift to the oscillator output for proper operation of the comparator **78** and also transforms the sinusoidal output of the oscillator into a square wave so that the comparator is switched on and off at precisely defined intervals. Thus, the oscillator **82** is made to generate an output which is in phase with the inversion tone contained in the received signal. At this point, both the complex code and the inversion tone have been regenerated, with proper phase, at the local receiver so that the voice communication may now be recovered from the scrambled, inverted signals.

The descrambling and reinversion of the received signal is performed in a pair of phase modulators **54** and **86**, respectively. Prior to the time that the code word and the inversion tone are supplied to these modulators, the output of the decoder consists of unintelligible, "garbled" signals. To prevent transmission of these signals to the output prior to decoding, the modulators **54** and **86** are keyed on by switches **72** and **88**, respectively.

The switch **72**, when on, passes the regenerated code word from the generator **70** to the modulator **54**, while the switch **88**, when on, passes the inversion tone from the oscillator **82** to the modulator **86**. These switches in turn are operated from a switch **90** through a low pass filter **92**. The switch **90** is driven from oscillator **82**. When the output of the oscillator **82** and the limiter **74** are in phase, the switch **90** is closed; this in turn closes the switches **72** and **88** and passes the code word and the inversion frequency tone through to the modulators **54** and **86**, respectively. It also supplies a signal to the amplifier stage in the filter and amplifier **64** to decrease the gain of the amplifier and thus switch the oscillator **66** to the synchronous frequency. The modulator **54** descrambles the communication and supplies as an output a signal comprising the inverted voice communication plus the inversion frequency tone. This signal is reinverted by the modulator **86** and then passed through a low pass filter **94** to an output utilization device, such as a speaker **96**. The modulator **86**, as well as the modulators **54** and **58**, may advantageously have the same construction as the modulators **18** and **28** in the transmitter.

The switches **72** and **88**, in addition to preventing a garbled output prior to the time that the complex code and the inversion tone have been regenerated at the receiver, serve the additional function of permitting through-transmission of uncoded signals. Thus, when each of the modulators **54** and **86** comprises a pair of transistors arranged in symmetric, balanced, configuration, the transistors function as ordinary amplifiers in the absence of a modulating signal applied to them. Accordingly, in the absence of a complex code component in the received signal, the modulators **54** and **86** merely amplify the received signal and pass it through to the output unchanged in other respects. When such a component is present in the received signal, they recover the original communication by successive remodulation. Thus, whether the received signal is scrambled or unscrambled, the output will always be a clear reproduction of the voice communication.

Instead of transmitting the complex word with the inverted, scrambled communication to thereby obtain a synchronization signal, it is possible to utilize the scrambled inversion tone itself as the sole synchronization signal and to reconstitute the inversion tone and the code receiver by cross-coupling the code synchronization loop and the phase-lock loop such that the output of the one serves as the input of the other. The modifications required to effectuate this are shown in dotted lines in FIGS. **1** and **2**. In FIG. **1**, the low pass filter **38** and summer **40** enclosed within the block **100** are omitted in the alternative embodiment and instead the output of the phase modulator **28** is connected directly to the transmitter **14** via the lead **102**. Thus, the code from the generator **32** is applied only to the amplifier **36** and is not applied to the transmitter **14**. Since the signal input to the modulator **28** is the sum of the inverted voice communication and the inversion tone, the output of this modulator is the inverted, scrambled voice communication plus the scrambled inversion tone which serves as a synchronizing signal for recovering the original communication at the receiver. Preferably, the synchronization component is at a level of approximately 25 percent of that of the communication component.

Referring now to FIG. **2**, the received signal, consisting of a communication component (the inverted, scrambled voice) and a synchronization component (the scrambled inversion tone) is first demodulated by the demodulator **52** (assuming the signal to have been modulated by the transmitter **14** prior to its transmission) and then applied to the phase modulators **54** and

58, previously described, as well as to an additional phase modulator **59** required in the alternative embodiment now being described. The modulator **59** is driven by the output of the phase lock loop **76** and supplies its output to the filter **56**. The lead **56'** which formerly connected the filter **56** to the demodulator **52** is removed in the present embodiment so that the sole input to the filter **56** is from the modulator **59**.

The communication and synchronization components of the demodulated input signal are mixed with the complex code word in the demodulator **58** and with the inversion tone in the demodulator **59**. Assume for the moment that the code synchronization loop **60** is locked to the code portion of the incoming synchronization signal so that the generator **70** drives the demodulator **58** with the regenerated complex code word. This is mixed with the communication and synchronization signal components applied to the demodulator to provide a first output comprising the inverted voice communication and a second output comprising the inversion tone, together with higher order modulation products. The inverted voice communication and the higher order modulation products are filtered out by the filter **74** so that only the pure inversion tone passes through the filter to drive the phase lock loop **76**. The inverted scrambled communication component, and all higher order components arising from demodulation of the synchronization component, are filtered out by the filter **56** so that the input to the synchronization loop consists primarily of the complex code. The synchronization loop **60** then regenerates this code sequence free of noise and distortion. This regenerated code, together with the regenerated inversion tone, is applied to the demodulators **54** and **86** respectively, which first descramble the communication component and then re-invert it in the manner previously described. The resultant signal is then passed through the low pass filter **94** for reproduction by the speaker **96**.

The alternative embodiment described above posseses certain advantages over the embodiment first described herein. Thus, the voice privacy device may readily be incorporated in a receiver which has a poor response in the low frequency ranges (0–300 Hz), since the synchronization component is entirely within the frequency band above this lower limit and thus is within the pass band of the receiver. Further, the system is more tolerant of frequency offset errors such as may occur in single sideband radio transmission or in transmission over ordinary telephone lines.

Finally, when the received signal is passed through the voice demodulators, the demodulation components due to the synchronization signal fall largely outside the voice passband and thus are not transmitted through the system with the descrambled speech; this results in a decreased background noise level.

From the foregoing, it will be seen that I have provided an improved voice privacy coder system which achieves a relatively high level of privacy while maintaining good fidelity of reproduction. This is due in part, in both embodiments to inversion of the voice-communication prior to scrambling with a complex code; this "pre-inversion" increases the scrambling level while allowing operation with fewer modulation products during the scrambling with the complex code word.

A synchronization signal within the frequency band of the transmitted voice communication and comprising, in one embodiment, the scrambled inversion tone plus the complex code word or, in the other embodiment, the scrambled inversion tone itself, is sent along with the transmitted communication and is separated into its component parts at the receiver so that the voice communication may be recovered. Embedding the synchronization signal within the communication signal in this manner further increases voice privacy.

The voice privacy coder systems of the present invention have been shown as embodied in a wireless transmitter-receiver combination. However, the invention is not so limited and the coders may advantageously be applied to other purposes, for example, to encoding and decoding communications which are to be transmitted over telephone lines. Further, any analog signal may be sent in privacy with the present invention, whether or not arising from a voice source. Other applications will suggest themselves to those skilled in the art.

Having described a preferred embodiment of the invention,

I claim:

1. Apparatus for encoding an analog communication in the audio frequency range for transmission to a remote receiver through a system having a bandwidth limited to the bandwidth of the analog communication, comprising:

A. means for inverting the analog communication around a frequency within the bandwidth of the communication;

B. means for adding a signal corresponding to the inversion frequency to the inverted communication to form a composite signal to be scrambled;

C. a code generator for repetetively generating a pseudo-random digital code word;

D. a phase modulator for scrambling said composite signal directly with said pseudo-random digital code word at a rate within the bandwidth of the communication; and

E. means for adding to the scrambled signal, prior to the transmission thereof, a synchronizing signal indicative of the phase of the complex code word, whereby said code may be regenerated at the remote receiver in synchronism with the modulating code at the transmitter.

2. Apparatus for decoding an analog communication which has been inverted and then scrambled directly with a complex code word prior to transmission to the decoding apparatus, and which includes synchronizing signal components corresponding to the inversion tone and the complex code word, said apparatus comprising:

A. means for generating a replica of the complex code word in synchronism with the code word used to scramble said communication;

B. means for generating a tone at the inversion frequency in synchronism with the tone with which the communication has been scrambled;

C. means for descrambling the coded communication with the generated code word;

D. means for re-inverting the unscrambled communication with the generated tone; and

E. means for preventing the descrambling or the reinverting of the coded communication prior to the generation of the code word replica and the inversion frequency tone at the receiver.

3. Apparatus for decoding an analog communication which has been inverted and then scrambled by phase-modulating it directly with a complex code word prior to transmission to the decoding apparatus, and which includes synchronizing signal components corresponding to the inversion tone and the complex code word, said apparatus comprising:

A. means for generating a replica of the complex code word in synchronism with the code word used to scramble said communication;
B. means for generating a tone at the inversion frequency in synchronism with the tone with which the communication has been scrambled;
C. means for descrambling the coded communication by phase-demodulating it with the generated code word in a balanced modulator having switching means associated therewith for inhibiting the application of the code replica to the modulator prior to the time that the replica has been synchronized with the code word component of the received coded communication, whereby the received communication is passed through said modulator without frequency translation in the absence of synchronization; and
D. means for re-inverting the unscrambled communication with the generated tone.

4. Apparatus for decoding an analog communication which has been inverted and then scrambled directly with a complex code word prior to transmission to the decoding apparatus, and which includes synchronizing signal components corresponding to the inversion tone and the complex code word, said apparatus comprising:

A. means for generating a replica of the complex code word in synchronism with the code word used to scramble said communication;
B. means for generating a tone at the inversion frequency in synchronism with the tone with which the communication has been scrambled, said means comprising:
   1. an oscillator supplying an output at a controllable rate,
   2. a phase comparator
      i. connected to the oscillator,
      ii. receiving a first input from the oscillator and a second input from the inversion tone component in the received coded signal,
      iii. supplying a first driving signal to the oscillator to shift its frequency in a direction such as to minimize the phase difference between the oscillator output and the inversion tone component in the received coded communication when the oscillator output and the inversion tone component are not synchronized with each other, and
      iv. supplying a second driving signal to the oscillator to maintain the oscillator frequency constant when the oscillator output and the inversion tone component are synchronized with each other;
C. means for descrambling the coded communication with the generated code word; and
D. means for re-inverting the unscrambled communication with the generated tone.

5. Apparatus according to claim 4 in which the inversion tone component of the received coded communication is scrambled with the inverted communication prior to transmission and is recovered from said communication by rescrambling said communication with the replica of the complex code word prior to applying said tone component to said phase comparator.

6. Apparatus for decoding an analog communication which has been inverted and then scrambled directly with a complex code word prior to transmission to the decoding apparatus, and which includes synchronizing signal components corresponding to the inversion tone and the complex code word, said apparatus comprising:

A. means for generating a replica of the complex code word in synchronism with the code word used to scramble said communication, said means comprising a code synchronizing loop having:
   1. a feedback shift register for generating a digital pattern, a digit at a time,
   2. an oscillator connected to said register to supply shift signals thereto at a controllable rate; and
   3. a correlator
      i. receiving a first input from the coded communication and a second input from the shift register,
      ii. supplying a first driving signal to the oscillator to shift its frequency in a direction such as to minimize the phase difference between the oscillator output and the code word component in the received coded communication, and
      iii. supplying a second driving signal for maintaining the oscillator frequency constant when the output of the shift register is synchronized with said component;
B. means for generating a tone at the inversion frequency in synchronism with the tone with which the communication has been scrambled;
C. means for descrambling the coded communication with the generated code word; and
D. means for re-inverting the unscrambled communication with the generated tone.

7. Apparatus according to claim 6 including:

A. means connected to the shift register for descrambling the coded communication with the code word replica prior to generation of the inversion tone, and
B. switch means
   1. responsive to the phase relation between the locally generated inversion tone and the inversion tone with which the communication has been encoded, and
   2. providing a switching command indicative of synchronization between the respective inversion tones.

8. A voice privacy communication system for the transmission of analog communications in privacy through a transmission channel having limited bandwidth, comprising:

A. a transmitter having
   1. means for inverting an analog communication in accordance with an inverting signal;
   2. means for adding a signal corresponding to the inverting signal to the inverted communication to form a composite signal for scrambling;
   3. means for scrambling the composite signal directly with a complex code word, and

4. means for including synchronizing signals within the encoded communication prior to transmission to a remote receiver; and

B. a receiver having

1. means for generating a replica of the complex code word in synchronism with the code word with which the communication has been scrambled,
2. means for unscrambling the received encoded communication with the complex code word replica,
3. means for generating a replica of the inverting signal in synchronism with the signal inverting the analog communication, and
4. means for reinverting the unscrambled communication in accordance with the inverting signal replica to recover the analog communication.

9. A communication system according to claim **8** in which the complex code word is added to the coded communication at a power level substantially less than the power level of the coded communication prior to transmission of said communication to the remote receiver.

10. A voice privacy communication system for the transmission of analog communications in privacy through a transmission channel having limited bandwidth, comprising:

A. a transmitter having

1. means for inverting an analog communication in accordance with an inverting signal,
2. means for scrambling the inverted communication directly with a complex code word, and
3. means for including synchronizing signals within the encoded communication prior to transmission to a remote receiver; and

B. a receiver having

1. means for generating a replica of the complex code word in synchronism with the code word with which the communication has been scrambled, said means comprising a code synchronizing loop having:
   i. a digital shift register in which the code word replica is stored and supplying outputs from at least two distinct portions of said word,
   ii. an oscillator applying shift signals to the register to shift the word position therein, and
   iii. means for comparing the phase of the replica with the phase of the code word component contained in the received communication, the comparing means providing a first output to control the frequency with which shift signals are applied to the shift register when the code word and its replica are not synchronized and providing a second output to fix the frequency with which the shift signals are applied to the shift register when the code word and its replica are synchronized;
2. means for unscrambling the received encoded communication with the complex code word replica,
3. means for generating a replica of the inverting signal in synchronism with the signal inverting the analog communication, and
4. means for reinverting the unscrambled communication in accordance with the inverting signal replica to recover the analog communication.

11. A communication system according to claim **10** in which the means for generating the replica of the inverting signal includes:

A. a controllable oscillator providing an output, and

B. a phase comparator

1. receiving the oscillator output as a first input and the unscrambled communication as a second input,
2. providing a first driving signal to the oscillator when the first and second inputs to the comparator are not synchronized in phase to thereby change the frequency of the oscillator output, and
3. providing a second driving signal to the oscillator when the first and second inputs to the comparator are synchronized in phase to thereby maintain the oscillator frequency constant.

12. A communication system according to claim **11** which includes switching means responsive to the oscillator output to prevent frequency translation of the unscrambled communication prior to the time that the code word replica and the inverting signal replica are generated in synchronism with their respective counterparts.

13. A communication system according to claim **10** which includes means for setting the oscillator to a first frequency prior to the time the complex code word is generated and for setting the oscillator to a second frequency after the code word is generated.

14. A communication system according to claim **13** in which the frequency setting means comprises means for supplying an offset bias in the code synchronizing loop in accordance with the presence or absence of a synchronizing signal indicating the achievement of synchronization.

15. Apparatus according to claim **13** including means for varying the loop gain in the code synchronizing loop in accordance with the presence or absence of a code synchronizing signal indicating the achievement of synchronization to thereby vary the noise bandwidth of the loop.

16. Apparatus for encoding an analog communication for transmission to a remote receiver, comprising:

A. means for inverting the analog communication around a selected frequency;

B. means for adding to the inverted communication a signal corresponding to the inversion frequency to form a composite signal to be scrambled.

C. a code generator for repetitively generating a pseudo-random digital code word; and

D. means for scrambling the composite signal directly with said code word to thereby provide synchronization and communication components, respectively for simultaneous transmission to a remote receiver over a common channel.

17. Apparatus according to claim **16** in which the means for inverting the communication comprises:

A. a modulator having the communication applied as a first input thereto and a tone at the inversion frequency as a second input thereto; and

B. a filter for eliminating the upper sideband from the modulated communication.

18. Apparatus according to claim **16** in which the means for scrambling the composite signal comprises a modulator having the composite signal applied as a first input thereto and the output of the code generator applied as a second input thereto.

19. Apparatus according to claim 16 in which the scrambled inversion tone comprises the sole synchronization signal transmitted to the remote receiver.

20. Apparatus according to claim 16 in which the inversion tone is added to the inverted communication prior to scrambling whereby the inverted communication and the inversion tone are both scrambled with the complex code simultaneously.

21. Apparatus according to claim 16 in which the means for scrambling the composite signal comprises a phase modulator having the composite signal applied as a first input thereto and the code word applied as a second input thereto.

22. Apparatus for decoding a scrambled composite signal formed from an inverted communication to which a tone at the inversion frequency has been added prior to scrambling, said apparatus comprising

A. a code synchronization loop providing as an output a regenerated version of the complex code at the remote receiver;

B. a phase lock loop providing as an output a regenerated version of the inversion tone in phase with the inversion tone carried in the synchronizing signal;

C. a first descrambler (i) having the scrambled composite signal applied as a first input thereto, (ii) having the output of the phase lock loop connected as a second input thereto, and (iii) supplying to the code synchronization loop an input comprising a reinverted version of the scrambled communication.

23. Apparatus according to claim 22 which includes a second descrambler (i) having the scrambled composite signal applied as a first input thereto, (ii) having the output of the code synchronization loop applied as a second input thereto, and (iii) supplying to the phase lock loop an input comprising a descrambled version of the inversion tone.

24. Apparatus according to claim 22 in which said inversion tone and said communication are scrambled by modulating them with said complex code word and in which said first and second descramblers respectively comprise modulators.

25. Apparatus according to claim 1 in which the modulators are phase modulators.

26. Apparatus according to claim 25 which includes first and second filters associated with the first and second modulators transmitting therethrough substantially only the code and inversion tone respectively, the remaining modulation components being blocked by said filters.

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