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METHOD AND APPARATUS FOR REPRODUCTION OF ANGULAR MAGNETIC RECORDING

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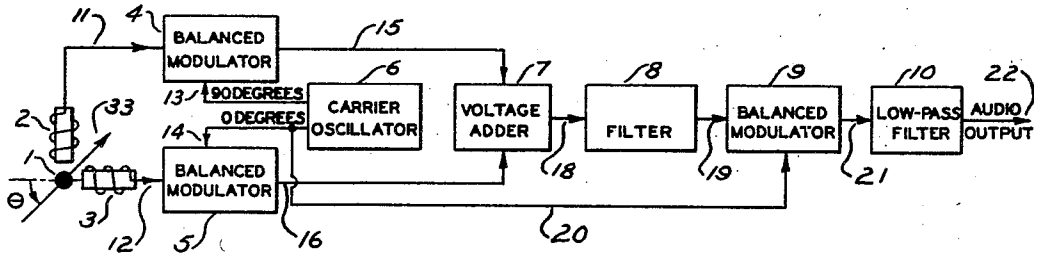


FIG. 1

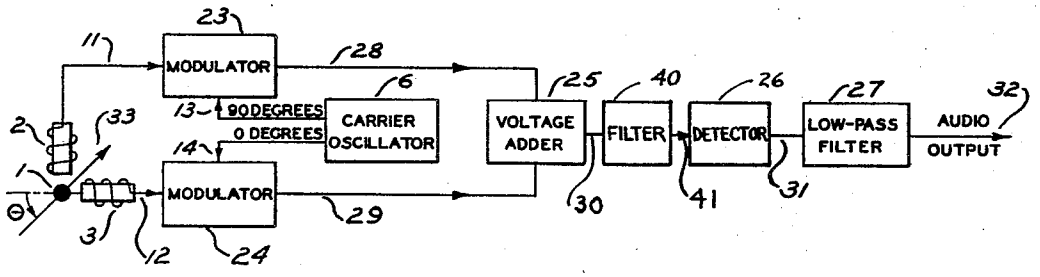


FIG. 2

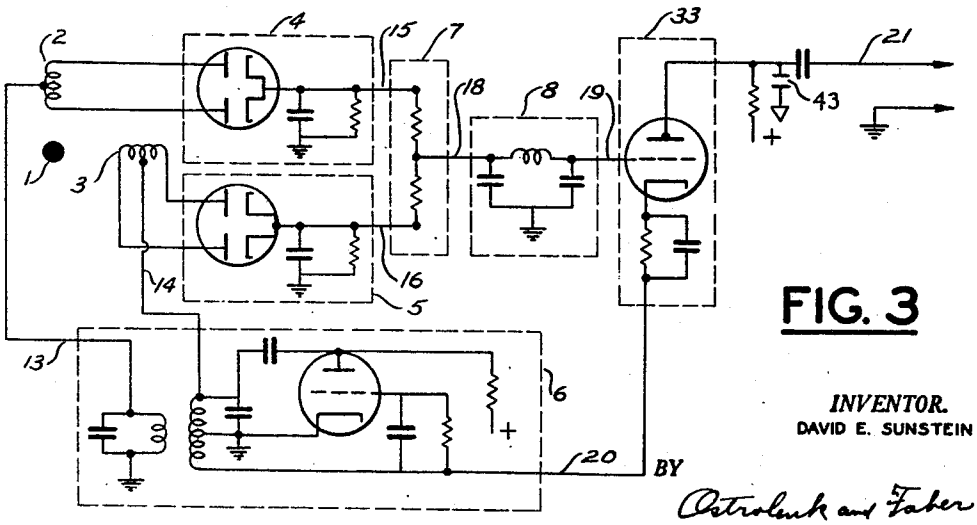


FIG. 3

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METHOD AND APPARATUS FOR REPRODUCTION OF ANGULAR MAGNETIC RECORDING

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My invention relates to systems for recording sound on steel or other magnetic wire. More particularly, it relates to the transverse method of recording, and provides a method for reproducing the fluctuations in magnetic flux into sound in such a manner that the variations which are caused by twisting of the wire are not reproduced.

In the method of transcribing and recording sound on steel wire by the transverse method, the magnetic flux at right angles to the axis of the wire is caused to vary along the wire in accordance with the tones of the sound being recorded. In this transverse method of recording the magnetic flux goes from one side of the wire through the wire to the other side, and thus on one side of the wire there will be a north pole at one particular spot and on the opposite side of the wire there will be a south pole. Halfway around the wire there will be neither a north pole nor a south pole, so no magnetic flux will emanate from the wire at this point.

If now, as the wire runs through the reproducing mechanism, the wire should twist on its axis, so that the reproducing pick-up coil should be pointed at the spot on the wire, half way between the north and the south pole, there would be no magnetic flux entering the pick-up coil, even though magnetic flux were present in the wire. This magnetic flux would then be at right angles to the pick-up coil, but no signal would be received. This is one of the major difficulties with the system of recording sound on round wire by the transverse method.

It is the purpose of my invention to provide a means for picking up the sound recorded on the wire independently of the twisting of the wire. In doing this I use two pick-up coils oriented at right angles to one another. In general, under these circumstances, each of the coils will pick up a signal from the wire, since the wire would be oriented with the maximum magnetic flux part way in between the two pick-up coils. Under two special circumstances, however, one of the coils would not have any voltage induced in it, that is, one coil would have maximum voltage induced in it and the other coil would have zero voltage induced in it, since this second coil would be opposite the point on the wire where there was no magnetic flux and from which there was no magnetic flux emanating. If the wire were twisted from this position by 90 degrees the roles of the two coils would be interchanged, that is the one which previously had maximum flux in it would now have zero flux

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in it, and the one which previously had zero flux through it would have maximum flux through it, and consequently, maximum induced voltage.

At first thought, it might appear that a simple addition of the voltages from these two coils would provide a solution to the problem. This, however, is not so, since there is a special position of the wire in which the voltages in the two coils oppose each other, and, thus, if they were added together, the result would be zero. Consequently, using a pair of pick-up coils, the system for combining the voltages induced into two pick-up coils must be more complicated than the simple addition process.

Furthermore, it must have the characteristics that as the two are added together, the relative magnitude of the voltages into two coils is unimportant. Another way of saying this is that as the two are added together the angle at which the magnetic axis of the wire rests with respect to the axis of either one of the coils must be unimportant as far as the output of the final system is concerned.

It is this type of a system which is the subject of the present application and generally set forth as follows: In order to accomplish this purpose, I transmit the signals from the two coils into two modulators, thus, superimposing these frequencies upon a carrier frequency.

The carriers used for these two modulators are of the same frequency, but are displaced one from the other by 90 electrical degrees (the pick-up coils are displaced with respect to one another by 90 mechanical degrees). By dephasing the carriers I can add the output signals on the two modulators in a voltage adder, and I find that the output of this votlage adder has the essential characteristics which I am looking for, namely, the angular position of the wire on which the recording is made does not enter into the amplitude of the output of the voltage adder.

This output signal from the voltage adder is, nevertheless, still a signal which has been superimposed on a carrier. The problem, then, is to demodulate this signal so that only the audio frequency will be present.

One of the several methods of doing this is to pass the output of the voltage adder through a band pass filter which removes one of the side band signals present in the output of the voltage adder, and then to pass this output through a detector which may also be supplied with the same carrier signal as was supplied to the modulators associated with the pick-up coils.

The output of this detector, then, will contain

a series of frequencies. One band of these frequencies will be the audio band which is desired, and this audio band can be separated by means of a low pass filter on the output of the detector. The output of this low pass filter, then, is the standard audio output which is desired.

When this system is described as I have done above, it seems that there are a considerable number of components to it. However, it is perfectly possible in designing such a system to incorporate in one unit several of the functions which I have described above.

Thus, for example, the low pass filter which separates the audio signal from the rest of the signals after the last detection or modulation can very readily be built in to the detector, or, if it is desired to amplify the output, it can readily be built into the characteristics of this amplifier, so that the amplifier itself would be an amplifier which will pass only audio frequencies and will not pass the supersonic frequencies, such as those which might be used for the carrier in this system.

Likewise, the voltage adder which has been mentioned above may very conveniently be merely a center tapped resistor, or may merely require the parallel or series connection of two signals, so that when the system is laid out in terms of individual components, that is tubes, resistors, capacitors, coils, etc., it is not unduly complicated. However, when the system is subjected to analysis, it will be found that in one way or another each one of the processes mentioned above has been carried out therein.

The fundamental purpose of my invention then is to provide a means for picking up the signals from a wire carrying transverse sound recording and to pick this signal up in such a way that it can be reproduced electronically independently of the twisting of the wire in the original recording.

Still another purpose of my invention is to provide a method for reproducing the signal transversely recorded on magnetic round wire in such a way that twisting of the wire does not introduce a difficulty. These purposes and other purposes of my invention will become more apparent after a study of the details of the invention. This is best carried out by reference to the figures in which:

Figure 1 shows a block diagram of one method of accomplishing my invention.

Figure 2 shows another block diagram of one method of accomplishing my invention, and

Figure 3 shows a detailed schematic diagram of one method of accomplishing my invention.

I now will make reference to Figure 1, and shall give an analysis of the performance of this system. The wire 1 upon which the sound is recorded is shown in cross section. An arrow 33 is drawn through this wire to show the direction in which the magnetic flux is existing at this particular instant. The angle θ is observed to be the angle between this flux 33 and the axis of one of the pickup coils 3. The other pick-up coil 2 is oriented at right angles to pick-up coil 3.

As the wire is fed through this pick-up system, it travels perpendicularly to the plane of the paper in this drawing. As it moves, variations in voltage are induced in coils 2 and 3 in accordance with the signal recorded on the wire. For the purposes of the analysis of this system I shall consider that the recording consists of a single frequency within the audio range but it is

applicable to a recording of a plurality of frequencies. This single frequency wave I shall represent as A cos MT.

Thus the signals induced in these two coils are given by the following two Equations 1 and 2:

(1) $e_{11}=A \sin \theta \cos Mt$

(2) $e_{12}=A \cos \theta \cos Mt$

It will be observed that these equations show the characteristics which I mentioned above. The strength of the signal picked up in coil 2 and put out on line 11 is given by Equation 1, and it is observed that the strength of this signal depends not only upon the amplitude of the signal recorded on the wire, but also upon the angle of twist of the wire. This is brought into the equation by the factor $\sin \theta$.

Likewise, the voltage on line 12 is given by Equation 2, and here again the angle θ enters in, but this time it comes in as the cosine function, i. e., $\cos \theta$.

The two signals are fed into the two balanced modulators 4 and 5. These balanced modulators are also fed with carrier signals from carrier oscillator 6. These two signals of carrier frequency are fed over lines 13 and 14. Line 13 has its carrier signal displaced 90 degrees from the carrier signal fed over line 14 by any of the well known means. Mathematically, this can be expressed by Equation 3 which gives the voltage on line 13 and by Equation 4 which gives the voltage on line 14:

(3) $e_{13}=B \sin ct$

(4) $e_{14}=B \cos ct$

The theory of the balanced modulator indicates that the output voltage of the modulator will be substantially the product of the two input voltages except for frequency components which are entirely outside the range here considered.

Thus, the output of balanced modulator 4 is given on line 15, and this votlage is as given in Equation 5:

(5) $e_{15}=AB \sin \theta \cos Mt \sin ct$

Likewise, the output on line 16 is given by Equation 6 as the product of Equation 2 and Equation 4:

(6) $e_{16}=AB \cos \theta \cos Mt \cos ct$

It will be noted that each of these contains the product of: the amplitudes of the carrier and the pick-up signals, a function of the angle of the wire, the audio frequency being picked up and the carrier frequency.

When Equations 5 and 6 are added together there is obtained the output of the voltage adder 7:

(7) $(e_{18}=AB \cos Mt (\sin \Theta \sin ct+\cos \Theta \cos ct)$

in which the term AB cos Mt has been factored out from the sum. By means of the well known trigonometric equivalents this equation can be rewritten in the form of Equation 8:

(8) $(e_{18}=AB \cos Mt \cos (ct-\Theta)$

Inspection of Equation 8 shows that the first purpose of the sequence has been accomplished, namely, that the angle of twist of the wires Θ appears as a phase angle in the carrier term, not as a phase angle in the amplitude term.

The remaining part of the system provides means for reducing this signal to an audio tone. In order to analayze the operation of the re-

mainder of the system, consider Equation 8 to be rewrittten in terms of its equivalents in the form of Equation 9:

$$(9)\quad e_{18}=\frac{AB}{2}\cos[(c-M)t-\theta]+\frac{AB}{2}\cos[(c+M)t-\theta]$$

in which the standard trigonometric formula for the product of the cosines has been used.

This splitting up of the Equation 8 shows that the signal on the output of the voltage adder can also be considered to be the sum of signals of two different frequencies, one of which is the carrier minus the audio frequency and the other of which is the carrier plus the audio frequency.

A filter **8** is used to eliminate one of these side band frequencies. This filter may pass either the lower or upper sideband, but in the following analysis, the filter is chosen as a low pass filter which eliminates the band above the carrier frequency. Thus, the output on line **19** is merely the first term in Equation 9 which is given in Equation 10:

$$(10)\qquad e_{19}=\frac{AB}{2}\cos[(c-M)t-\theta]$$

This signal is fed into another balanced modulator **9**, which serves as a demodulator or detector. Likewise, into this modulator is fed a signal from the carrier oscillator. In order to be specific, I shall make the following analysis with this signal from the carrier oscillator being fed from the same line **14** which feeds balanced modulator **5**. This, however, is an unimportant detail since carrier signal of any phase fed into this balanced bodulator **9** will be satisfactory. Thus, the output of balanced modulator **9** is substantially the product of the signal on line **19** and a signal on line **20** (which is the same as the signal on line **14**). The output of balanced modulator **9** is given by Equation 11, the product of Equations 4 and 10:

$$(11)\qquad e_{21}=\frac{AB^2}{2}\cos ct\cos[(c-M)t-\theta]$$

Again employing the formula for the product of two cosines, this Equation 11 can be changed to Equation 12:

$$(12)\quad e_{21}=\frac{AB^2}{4}\cos[Mt+\theta]+\frac{AB^2}{4}\cos[(2c-M)t-\theta]$$

Inspection of this equation shows that there is one term which contains the audio frequency only, and another term which contains a frequency of twice the carrier frequency minus the audio frequency. If the carrier frequency is sufficiently high, this second term can be removed by low pass filter **10**, so that the output on line **22** is only the first term of Equation 12, as given in Equation 13:

$$(13)\qquad e_{22}=\frac{AB^2}{4}\cos(Mt+\theta)$$

It is to be observed that this equation contains the angle of the orientation of the wire as a phase angle in the audio frequency. Reasonable amounts of distortion in the angle of the wire will be of no importance in disturbing the output signal.

Another method for carrying out a similar procedure is shown in Figure 2. Here the modulators are not balanced, so the outputs of these modulators **23** and **24** contain in addition to sde band signals, the carrier wave. This permits line **20** of Figure 1 to be omitted in Figure 2. The outputs of the modulators are fed through lines

28 and **29** into a voltage adder **25**. This is fed over line **30** into a filter **40**, which removes one side band. The output of this filter is fed over line **41** to detector **26** which may be a square law detector. The operation of this system gives as the output of the detector the audio frequency component similar to that shown in Equation 13, along with carrier frequency components and frequencies in that vicinity. These high frequencies are filtered out by low pass filter **27** and the audio output appears on line **32**.

Still another arrangement and combination of this system is shown in Figure 3. Here the blocks are broken down to show possible configurations of the components within the blocks. This diagram is patterned after the block diagram of Figure 1 with modifications. The pick-up coils **2** and **3** are shown in Figure 1. Each of the balanced modulators **4** and **5** contain a pair of diodes and load resistors and condensers. The balance modulators shown in Figure 3 are balanced for the modulating signal, whereas the ones described in connection with Figure 1 are balanced for carrier signals. The voltage adder **7** consists of a pair of resistors. The filter **8** is a standard low pass filter and the oscillator **5** is a standard tickler coil feed back oscillator.

In place of balanced modulator **9**, however, I have inserted into this diagram a plate detection device **33**. In this device the carrier signal is fed over line **20** to the cathode of the tube and the combined signal defined in Equation 10 is fed over line **19**. This is equivalent to supplying the grid circuit of the tube with a signal such as Equation 10, plus Equation 4 which is the carrier signal by itself. Since this detector works on a square law, it becomes necessary to determine the square of the input to this detector. This input is given by Equation 14:

$$(14)\qquad e_{33}=\frac{AB}{2}\cos[(c-M)t-\theta]+D\cos ct$$

where D cos *ct* is the effective carrier signal supplied to the detector **33**; that is, the vectorial difference in carrier level on lines **19** and **20**.

It is seen that when this is squared, the squares of the individual terms will yield frequencies which are all above the carrier frequency range, that is the frequencies which will be provided by these squared terms will be twice the frequencies of the terms themselves, and in addition there will be a steady D. C. component which will be unimportant.

However, the cross product of the two terms which is given by the square law detector also turns out to be the same as that given for e_{21} in Equation 11. Naturally, this signal can be rearranged in accordance with Equation 12, and when the frequencies above the audio range are eliminated by a filter, the remaining signal will be that shown in Equation 13 which is the desired signal and is the same signal that came out of the circuit of Figure 1.

In this particular schematic diagram of Figure 3, a simple capacitor **43** is shown as an audio low pass filter after the detector, in addition to the coupling circuit indicated. This simple low pass circuit is adequate since the audio amplifier and sound reproducing systems will not respond to frequencies above the audio range anyway.

The above analysis was carried out considering only a single wave for the audio frequency. If, however, in Equations 1 and 2 we introduce cos M_1t plus cos M_2t, we find that in the output of the balanced modulators **5** and **6** there is ob-

tained only a pair of additive terms similar to Equations 5 and 6; i. e., there is obtained a term M_1 similar to that in Equation 5 plus another term with M replaced by M_2. Such a pair of terms would follow on through the analysis until Equation 13 is reached, though there would be no cross modulation between various audio-frequencies.

Thus, it becomes evident that a purpose of my invention is to provide means for obtaining the output from a magnetized wire without amplitude variations being caused by the angle of twist of the wire. This I have accomplished in the systems which I have disclosed here by the process of taking output from two coils placed at right angles and by properly combining these with a carrier, adding them, and then by properly reducing these modulated carrier signals to audio signals again. Since there are several combinations of circuits which will accomplish this basic idea, I prefer not to have my invention described and limited by the above description, but to have it described by the following claims.

I claim:

1. In a magnetic wire reproducing system in which transverse recordings are utilized on the magnetic wire, a plurality of pick-up coils angularly disposed about said wire, output circuits for each of said coils and means for producing signals modulated in accordance with the signal output of said pick-up coils and means for adding said modulated signals.

2. In a magnetic wire reproducing system in which transverse recordings are utilized on the magnetic wire, a plurality of pick-up coils angularly disposed about said wire, output circuits for each of said coils, a first and second carrier frequency means for modulating each carrier individually by one of said signal output circuits from said pick-up coils and means for adding said modulated signals.

3. In a magnetic wire reproducing system in which transverse recordings are utilized on the magnetic wire, a plurality of pick-up coils angularly disposed about said wire, output circuits for each of said coils, a first and second carrier wave of the same frequency, means for modulating each carrier individually by an associated one of said signal output circuits from said pick-up coils, and means for adding said modulated signals.

4. In a magnetic wire recording system in which transverse recordings are utilized on the magnetic wire, a pair of pick-up coils displaced from each other about said wire by 90 mechanical degrees; output circuits for each of said coils, a first and second carrier wave of the same frequency but displaced one from the other by 90 electrical degrees, means for modulating each carrier individually by an associated one of said signal output circuits from said pick-up coils and means for adding said modulated signals.

5. In a magnetic wire recording system in which transverse recordings are utilized on the magnetic wire, a pair of pick-up coils displaced from each other about said wire by 90 mechanical degrees; output circuits for each of said coils, a first and second carrier wave of the same frequency but displaced one from the other by 90 electrical degrees, means for modulating each carrier individually by an associated one of said outputs from said pick-up coils, means for adding said modulated signals, and means for demodulating the resultant, so that only the audio frequency recorded on the wire remains.

6. In a magnetic wire recording system in which transverse recordings are utilized on the magnetic wire, a pair of pick-up coils displaced from each other about said wire by 90 mechanical degrees; output circuits for each of said coils, a first and second carrier wave of the same frequency but displaced one from the other by 90 electrical degrees, means for modulating each carrier individually by the output of an associated one of said pick-up coils, means for adding said modulated signals, and means for demodulating the resultant, so that only the audio frequency recorded on the wire remains, comprising a band pass filter and a detector connected in the output of said adder means.

7. In a magnetic wire reproducing system in which transverse recordings are utilized on the magnetic wire, a plurality of pick-up coils angularly disposed about said wire, output circuits for each of said coils, a balanced modulator connected in each of said output circuits and an oscillator for feeding said modulators.

8. In a magnetic wire recording system in which transverse recordings are utilized on the magnetic wire, a pair of pick-up coils displaced from each other about said wire by 90 mechanical degrees; output circuits for each of said coils, a balanced modulator connected in each of said output circuits and an oscillator for feeding said modulators, the signal currents to said modulators from said oscillator being displaced 90 electrical degrees from each other.

9. In a magnetic wire recording system in which transverse recordings are made on the magnetic wire, a pair of pick-up coils displaced from each other about said wire by 90 mechanical degrees; output circuits for each of said coils, a balanced modulator connected in each of said output circuits and an oscillator for feeding said modulators, the signal currents to said modulators from said oscillator being displaced 90 electrical degrees from each other, and a voltage adder connected in the output circuits of said balanced modulators.

10. In a magnetic wire recording system in which transverse recordings are made on the magnetic wire, a pair of pick-up coils displaced from each other about said wire by 90 mechanical degrees; output circuits for each of said coils, a balanced modulator connected in each of said output circuits and an oscillator for feeding said modulators, the signal currents to said modulators from said oscillator being displaced 90 electrical degrees from each other, and a voltage adder connected in the output circuits of said balanced modulators, and a demodulator connected in the output of said voltage adder.

11. In a magnetic wire recording system in which transverse recordings are utilized on the magnetic wire, a pair of pick-up coils displaced from each other about said wire by 90 mechanical degrees; output circuits for each of said coils, a balanced modulator connected in each of said output circuits and an oscillator for feeding said modulators, the signal currents to said modulators from said oscillator being displaced 90 electrical degrees from each other, a voltage adder connected in the output circuits of said balanced modulators, filter means connected in the output circuit of said adder for filtering thru one of the side band outputs therein, and a demodulator connected to the output of said filter means.

12. The method of reproducing signals from a magnetic wire recording which comprises electromagnetically producing signals which vary in accordance with the recording and as a function of

the angle of transverse recording axis and thereafter electrically eliminating from the reproduced signal those signals which are a function of the transverse angle of recording.

13. In a magnetic wire reproducing system in which transverse recordings are utilized on a magnetic wire, magnetic reproducing means for picking up signals varying in accordance with the recording and varying in accordance with the angle of the transverse recording with respect to the reproducing means and electronic means for producing from said picked up signals, signals varying only in accordance with the recording.

14. In a magnetic wire reproducing system in which transverse recordings are made on magnetic wire, a plurality of pick-up coils angularly disposed about said wire, each of said coils having an output circuit and each of said coils being energized by the component of the signal recording on the wire determined by the angular position of the axis of the coil with respect to the direction of the flux of the recording, a source of oscillations for each of said coils, the oscillations for one of said coils being phase displaced with respect to the oscillations for the other of said coils in amounts depending on the physical angular displacement of said coils with respect to each other, and means including the output circuits of each of said coils for modulating said oscillations in accordance with the signals flowing in the output circuits of said coils.

15. In a magnetic wire reproducing system in which transverse recordings are made on magnetic wire, a plurality of pick-up coils angularly disposed about said wire, each of said coils having an output circuit and each of said coils being energized by the component of the signal recording on the wire determined by the angular position of the axis of the coil with respect to the direction of the flux of the recording, a source of oscillations for each of said coils, the oscillations for one of said coils being phase displaced with respect to the oscillations for the other of said coils in amounts depending on the physical angular displacement of said coils with respect to each other and being 90° displaced from each other when the axes of said coils are 90° physically displaced, and means including the output circuits of each of said coils for modulating said oscillations in accordance with the signals flowing in the output circuits of said coils.

16. In a magnetic wire reproducing system in which transverse recordings are made on magnetic wire, a plurality of pick-up coils angularly disposed about said wire, each of said coils having an output circuit and each of said coils being energized by the component of the signal recording on the wire determined by the angular position of the axis of the coil with respect to the direction of the flux of the recording, a source of oscillations for each of said coils, the oscillations for one of said coils being phase displaced with respect to the oscillations for the other of said coils in amounts depending on the physical angular displacement of said coils with respect to each other, means including the output circuits of each of said coils for modulating said oscillations in accordance with the signals flowing in the output circuits of said coils, and means for combining said modulated signals and producing a resultant audio signal in accordance with the recordings and independent of the flux angle of said recordings with respect to the axis of any reproducing coil.

17. In a magnetic wire reproducing system in which transverse recordings are made on magnetic wire, a plurality of pick-up coils angularly disposed 90° apart about said wire, each of said coils being energized by the component of the signal recording on the wire determined by the angular position of the axis of the coil with respect to the direction of the flux of the recording, a source of oscillations, and means including said output signals of said coils for modulating said oscillations, the oscillations for the output of one of said coils being 90° phase displaced from the oscillations for the other of said coil outputs in amounts depending on the physical angular displacement of said coils with respect to each other.

18. In a magnetic wire reproducing system in which transverse recordings are made on magnetic wire, a plurality of pick-up coils angularly disposed about said wire, each of said coils having an output circuit and each of said coils being energized by the component of the signal recording on the wire determined by the angular position of the axis of the coil with respect to the direction of the flux of the recording, a source of oscillations for each of said coils, the oscillations for one of said coils being phase displaced with respect to the oscillations for the other of said coils in amounts depending on the physical angular displacement of said coils with respect to each other, means including the output circuits of each of said coils for modulating said oscillations in accordance with the signals flowing in the output circuits of said coils, a voltage adder, and means for applying the modulated signals produced by the output of each of said coils, and means for demodulating the resultant signal in the output of said voltage adder.

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REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,707,260	Fetter	Apr. 2, 1929
1,828,189	Kiliani	Oct. 20, 1931
2,245,286	Marzocchi	June 10, 1941

FOREIGN PATENTS

Number	Country	Date
593,565	Germany	Feb. 28, 1934