Sept. 5, 1961

D. E. WIEGAND

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FLUX GATE TRANSDUCER

Filed March 3, 1955

5 Sheets-Sheet 1

Fig. 1

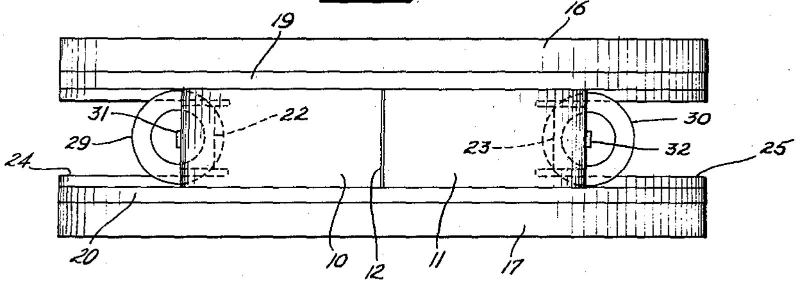


Fig. 2

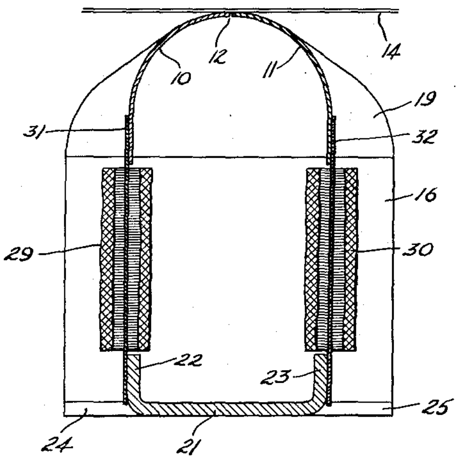


Fig. 3

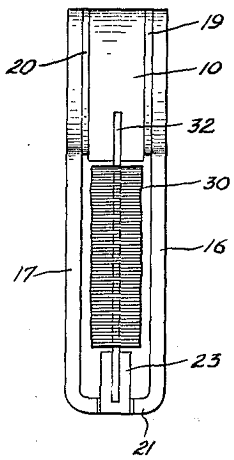
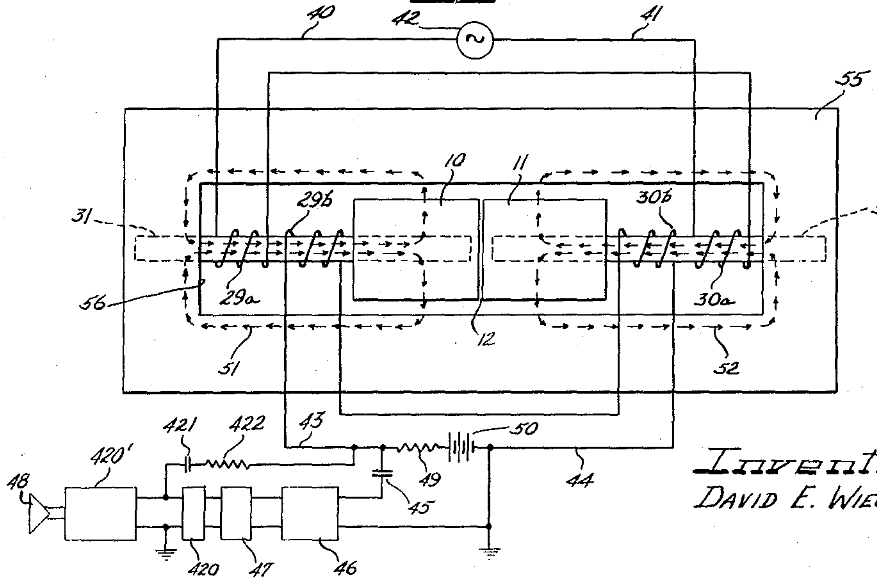


Fig. 4



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Sept. 5, 1961 D. E. WIEGAND **2,999,135**

FLUX GATE TRANSDUCER

Filed March 3, 1955

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Fig. 5

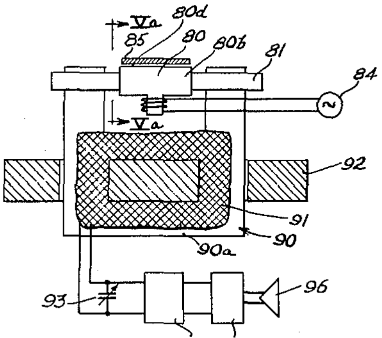


Fig. 5a

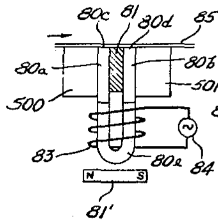


Fig. 5b

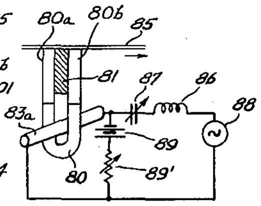


Fig. 6

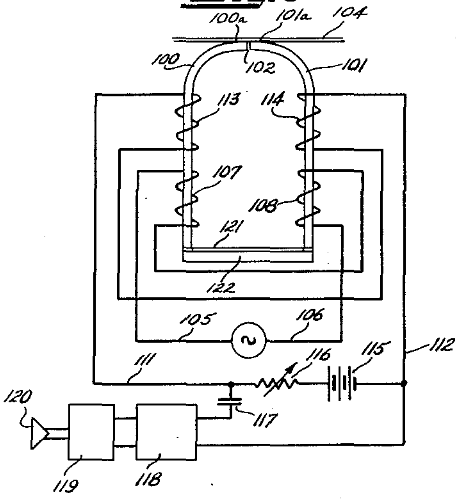


Fig. 7

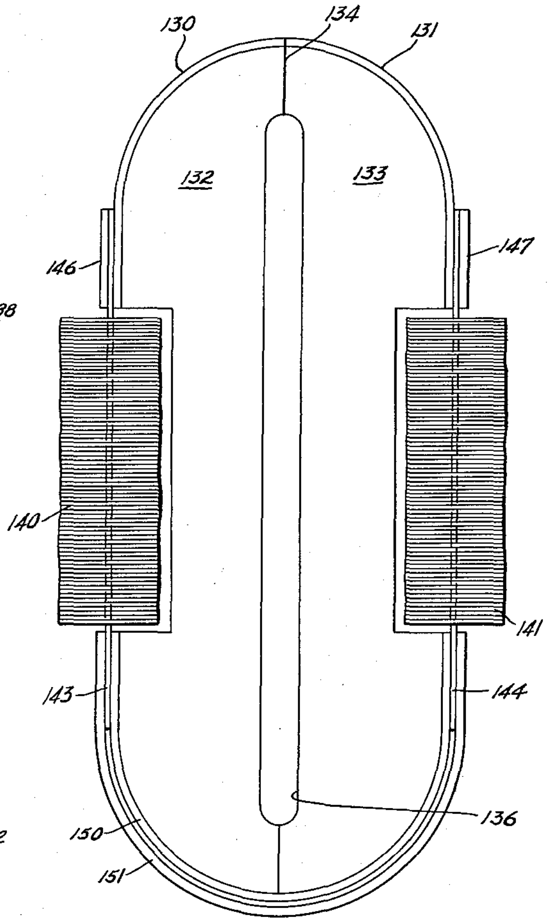
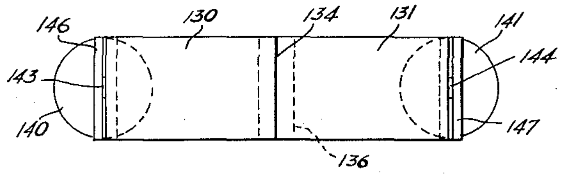


Fig. 8



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FLUX GATE TRANSDUCER

Filed March 3, 1955 5 Sheets-Sheet 3

Fig. 9

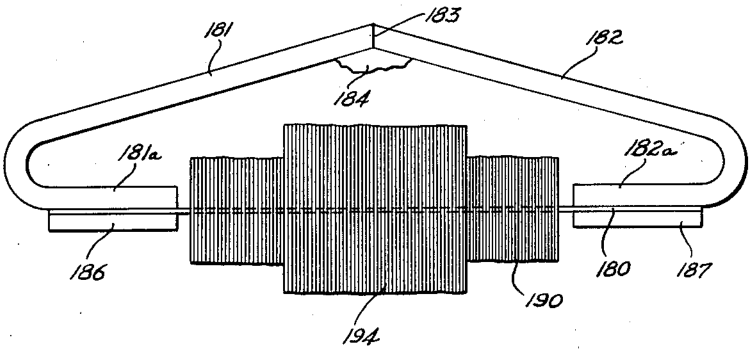

Fig. 10

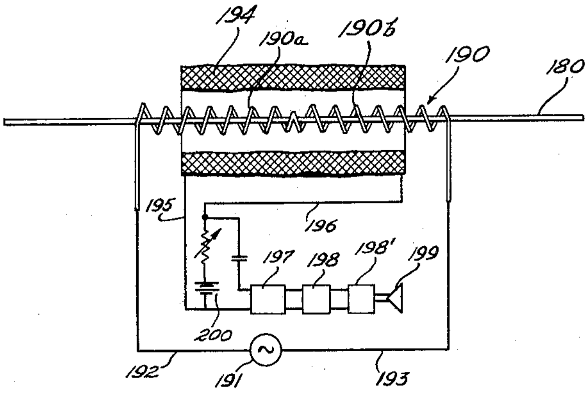

Fig. 11

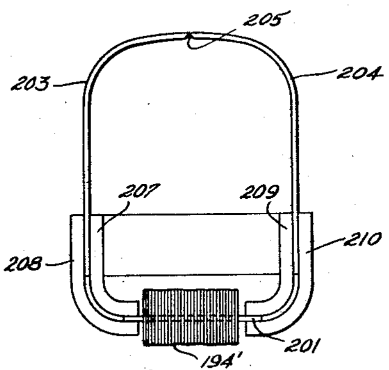

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Fig. 12

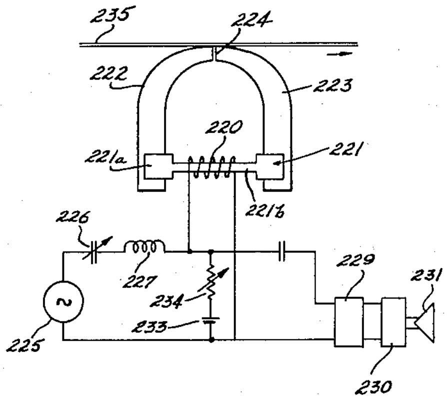


Fig. 13

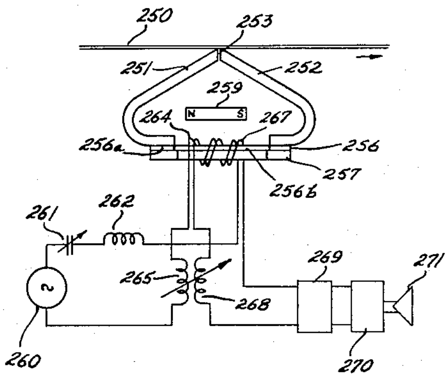


Fig. 14

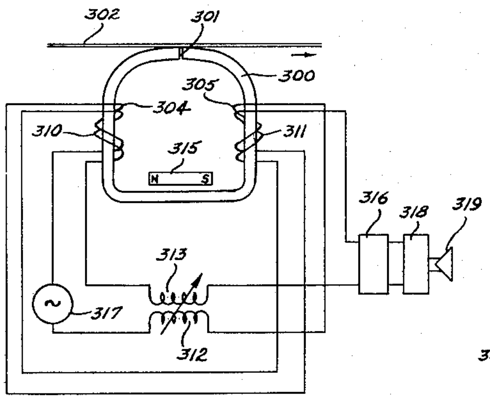
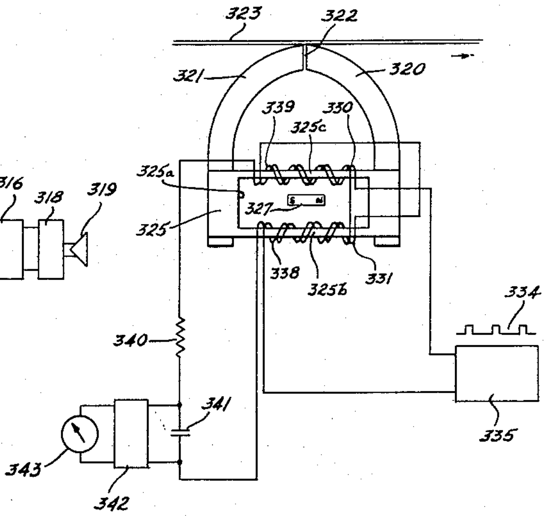


Fig. 15



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FLUX GATE TRANSDUCER

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Fig. 16

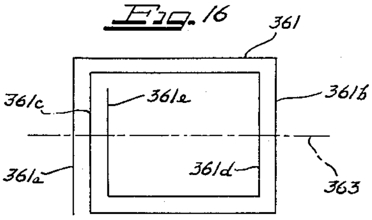


Fig. 18

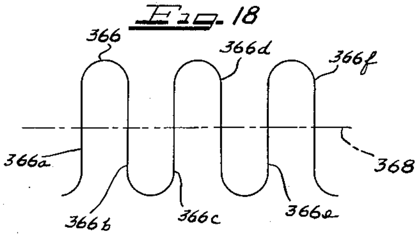


Fig. 17

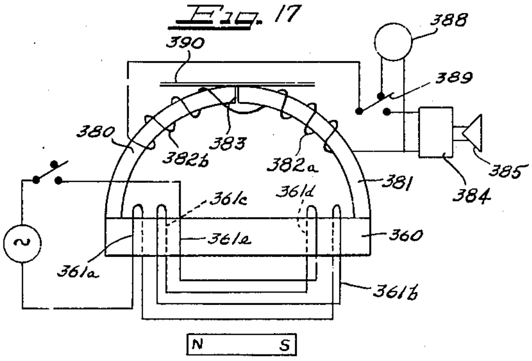


Fig. 19

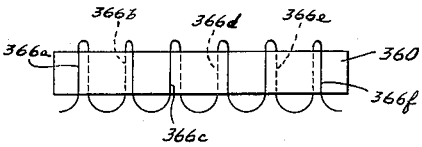


Fig. 21

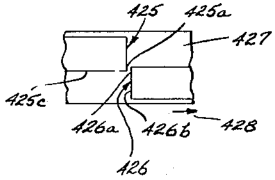
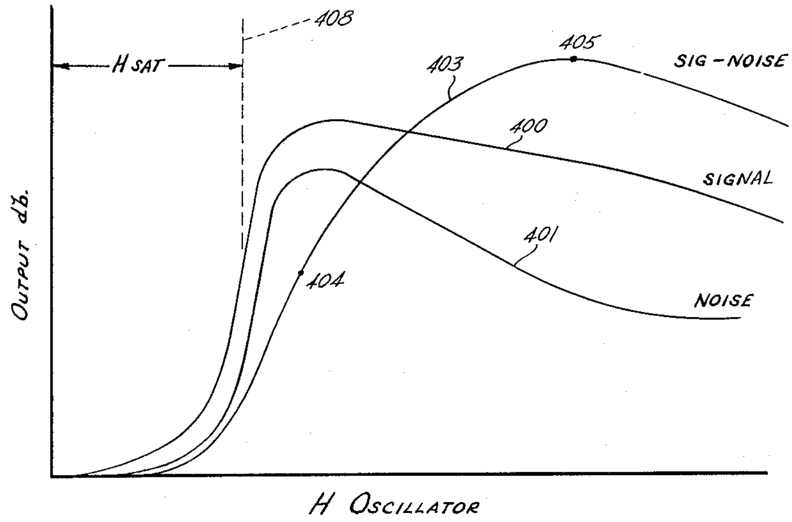


Fig. 20



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nited States Patent Office

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2,999,135
FLUX GATE TRANSDUCER

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Filed Mar. 3, 1955, Ser. No. 492,013
4 Claims. (Cl. 179—100.2)

The present invention is concerned with an improved electromagnetic transducing head and method, and is particularly directed to an electromagnetic reproducing head capable of response directly to magnetic flux rather than to rate of change of flux.

An object of the present invention is to provide an improved magnetic transducing assembly which is sensitive directly to magnetic flux rather than to the rate of change thereof.

Another object of the present invention is to provide an improved magnetic reproducing head capable of detecting recorded signals of variable frequency, including zero frequency.

Another object of the present invention is to provide an improved magnetic reproducing head and method providing a substantially higher signal output than conventional magnetic recording heads.

A further object of the present invention is to provide a novel magnetic modulator head and method usable for the reproduction of music and other signals requiring a high signal-to-noise ratio.

A still further object of the present invention is to provide a magnetic modulator head of novel and improved construction.

The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claims. My invention itself, however, as to its organization, manner of construction and method of operation, together with further objects and advantages thereof may be best understood by reference to the following description, taken in connection with the accompanying drawings, in which:

FIGURE 1 is a somewhat diagrammatic top plan view of a first electromagnetic transducer head according to the present invention;

FIGURE 2 is a longitudinal sectional view of the head of FIGURE 1;

FIGURE 3 is an end elevational view of the head of FIGURE 1;

FIGURE 4 is a diagrammatic view illustrating the energizing and output circuits for the head of FIGURE 1;

FIGURE 5 is a diagrammatic sectional view of a second form of electromagnetic transducer head according to the present invention;

FIGURE 5*a* is a diagrammatic cross sectional view taken along the line V*a*—V*a* of FIGURE 5;

FIGURE 5*b* is a diagrammatic view similar to FIGURE 5*a*, but showing a modified energizing circuit.

FIGURE 6 is a diagrammatic view illustrating a third form of head construction;

FIGURE 7 is a diagrammatic side elevational view of a further head construction according to the present invention;

FIGURE 8 is a top plan view of the head of FIGURE 7;

FIGURE 9 is a diagrammatic side elevational view of a still further head constructed in accordance with the principles of the present invention;

FIGURE 10 is a diagrammatic view illustrating the energizing and output circuits for the head of FIGURE 9;

FIGURE 11 is a diagrammatic side elevational view of a further head construction;

FIGURE 12 is a diagrammatic side elevational view of a still further modification;

FIGURE 13 is a diagrammatic side elevational view of a further head construction utilizing a unidirectional high frequency winding on a saturating strip;

FIGURE 14 illustrates a modification utilizing high frequency windings connected in aiding relation with respect to the gap and operating on the incremental permeability characteristics of the record member;

FIGURE 15 illustrates a magnetic head excited by a high frequency pulse generator;

FIGURES 16 and 17 illustrate a manner of applying a winding to a staturating strip without wrapping the winding completely around the saturating strip;

FIGURES 18 and 19 illustrate a further manner for exciting a saturating strip without the use of a winding completely encircling the strip;

FIGURE 20 represents graphically the signal and noise output from a head according to the present invention as a function of the applied intensity of magnetization from the oscillator; and

FIGURE 21 is a diagrammatic illustration of a magnetic head having laterally offset poles.

As shown on the drawings:

Referring to FIGURES 1 through 4, there is illustrated a shielded transducer head construction according to the present invention.

The head comprises a pair of pole shoes **10** and **11** which are illustrated as being of the confronting type to define therebetween a non-magnetic gap **12**. The pole pieces are shaped to provide tape contacting surfaces for receiving a tape magnetic record member **14** in proximity to the non-magnetic gap **12**. The pole shoes **10** and **11** are secured in any suitable manner within a housing which includes a pair of Mumetal shield plates **16** and **17**, non-magnetic spacers **19** and **20** insulating the pole shoes from the shield plates. The shield plates **16** and **17** may be provided from an integral strip of magnetic material formed into a generally U-shape with a base portion **21** of the U being formed with upstanding lugs **22** and **23**, the lugs being formed from the material of slots **24** and **25** in the base **21**.

Windings **29** and **30** are mounted on saturating members **31** and **32** which bridge between the pole shoes **10** and **11** and the lugs **22** and **23** to complete a single loop magnetic circuit including the base portion **21** and the gap **12**.

Referring to FIGURE 4, winding portions **29*a*** and **30*a*** of windings **29** and **30**, respectively, are connected in series opposing relation between leads **40** and **41** from a suitable oscillator **42** which is capable of generating a signal of frequency substantially above the frequencies to be reproduced from the magnetic impulse record member **14**, the output of the high frequency source being, for example, on the order of 228 kilocycles per second. While there are a number of suitable ways for obtaining a signal from the head construction of FIGURES 1–4, FIGURE 4 illustrates winding portions **29*b*** and **30*b*** of windings **29** and **30**, respectively, providing pickup windings connected in series aiding relation with respect to output leads **43** and **44**. The output signal from leads **43** and **44** may be delivered through a condenser **45**, an amplifier **46**, and a detector **47** to an output device such as loudspeaker **48**. The high frequency excitation windings **29*a*** and **30*a*** are preferably connected in series opposing relation with respect to the magnetic circuit as illustrated so as to avoid the generation of a net high frequency field at the non-magnetic gap.

A D.C. polarizing flux may be introduced into the magnetic circuit by means of resistor **49** and battery **50** to unbalance the high frequency fluxes in the magnetic circuit. With such a polarizing flux, the polarity of the output from the detector **47** will vary in accordance with the recorded signal. The level of D.C. polarizing flux is preferably higher than the maximum signal flux in the saturating strips to avoid distortion. In the absence of a D.C. bias flux, the output signal can be passed through a phase demodulator or phase sensitive rectifier so as to obtain an output the amplitude of which varies in accordance with the polarity of the recorded signal. The phase demodulator may comprise a full wave rectifier network with the amplified output from the pickup windings **29*b***, **30*b*** transformer coupled to one pair of terminals and a double frequency reference signal transformer coupled to the other pair of terminals of the rectifier network, the output being taken between center taps on the secondaries of the two transformers. The rectifier network may comprise four rectifiers connected in aiding relation about a closed circuit with the transformer secondaries each connected between one pair of opposite terminals of the network. A suitable phase demodulator is shown in my copending application Serial No. 294,684 of which the present application is a continuation-in-part.

As illustrated by the arrows **51** and **52** in FIGURE 4, the excitation windings **29*a*** and **30*a*** produce oppositely directed fluxes in the magnetic circuit including the saturating strips **31**, **32** and pole pieces **10** and **11** so that the high frequency fluxes may balance out at the gap **12**. As diagrammatically indicated in FIGURE 4, the high frequency flux paths **51** and **52** may include portions of the magnetic shield members, here indicated as a single flat plate **55** with a rectangular central slot at **56**. In the construction of FIGURES 1–3, it will be apparent that the leakage high frequency flux paths for each winding includes portions of each of the shield plates **16** and **17**.

It has been discovered that the cross section of the saturating strips **31** and **32** is critical to a satisfactory signal-to-noise ratio for certain applications, and that such a satisfactory signal-to-noise ratio is obtained by substantially reducing the cross-sectional area of the saturating parts. Further, it has been found that, within limits, the strength of the useful signal from the head is essentially unaffected by this reduction in cross-section.

More specifically, I have found that the optimum signal-to-noise ratio and linear operation are obtained when the saturating parts **31** and **32** are narrowed down so that a maximum signal on the tape **14** will produce a flux density in the saturating members **31** and **32**, which when added to any polarizing flux density is within the range between ⅓ and ⅔ of the value of intrinsic saturation induction for the material of the saturating members. In other words, the maximum flux capacity of the record medium plus the polarizing flux equals ⅓ to ⅔ of the product of the value of the saturation induction for the material of the saturating members and the cross section thereof.

By way of example, a specific head construction according to the embodiment of FIGURES 1–4 may comprise a pair of .006 inch thick by .060 inch wide "Mumetal" pole shoes, .010 inch thick insulating spacers, .020 inch thick "Mumetal" shield plates, and saturator strips of .001 inch thick by .010 inch wide by .380 inch long "Molypermalloy." "Mumetal" may comprise an alloy of 5% copper, 2% chromium, 77% nickel, and the remainder iron and minor constituents, while "Molypermalloy" or "Molybdenum Permalloy" may comprise 4% molybdenum, 79% nickel and the remainder iron and minor constituents.

FIGURES 5 and 5*a* illustrate a head construction including a magnetic core portion formed from a magnetic lamination **80** of block I configuration folded about a conductor strip **81** to provide enlarged cross-section pole portions **80*a*** and **80*b*** having upper edges **80*c*** and **80*d*** for receiving a tape magnetic record member successively thereacross. The connecting portion of the core **80*e*** (the vertical part of the "I") is of reduced cross-section such that a maximum signal on the tape will produce a flux density in the saturating portion **80*e*** which when added to the polarizing flux density therein produced by magnet **81′** is preferably of the order of ⅓ the value of saturation induction for the material of the lamination **80**.

The lamination **80** may have an exciting winding **83** thereon connected with an oscillator **84** for establishing bucking magnetic fields at the gap between poles **80*a*** and **80*b***. FIGURE 5*b* illustrates a modification wherein a high frequency conductor **83*a*** links the magnetic circuit provided by lamination **80** to establish a circulating high frequency flux in the lamination and across the gap between poles **80*a*** and **80*b***. The value of circulating flux is selected to be too low to erase the signal on the record member **85**. Such a circulating flux will still provide the desired magnetic modulator action. As indicated, the exciting conductor **83*a*** is preferably energized through an inductance **86** and condenser **87** tuned to the frequency of oscillator **88**. The second harmonic output is then obtained from pickup conductor **81** in the same manner as in FIGURE 5*a* to be now described. Polarizing flux may be supplied by means of battery **89** and resistor **89′**. The oscillator **88** and battery may be connected to conductor **81** if desired, and conductor **83*a*** omitted.

It will be observed that the conducting strip **81** forms a portion of a single turn primary winding **90** which is coupled to a high impedance secondary winding **91** on a transformer core **92** by means of a U-strap **90*a***. The transformer construction may be similar to that shown in my Patent 2,585,065. The secondary winding **91** of the transformer is tuned by means of a variable capacitance **93** to the second harmonic of the oscillator frequency from **84** in FIGURE 5*a* (or from oscillator **83** in FIGURE 5*b*), and the output is delivered to a tuned amplifier **94** and detector **95** for driving a suitable output device such as a loud speaker **96**. As previously, if no D.C. polarizing flux is introduced into the core **80**, the detector **95** must take the form of a phase demodulator for obtaining an output with polarity varying in accordance with the recorded signal on the tape.

FIGURE 6 illustrates a further form of modulator head wherein the magnetic circuit has a gap therein between a pair of pole shoes **100** and **101**. The upper edges **100*a*** and **101*a*** have a non-magnetic gap **102** therebetween and receive a record member **104** thereacross as in the embodiment of FIGURES 1–4. Leads **105** and **106** connected to series opposing coils **107** and **108** are preferably excited with a high frequency signal, while leads **111** and **112** are connected with series aiding coils **113** and **114** which are utilized to pick up the output signal. Bias is applied by means of battery **115**, and resistor **116**, while the output is taken through condenser **117**, tuned amplifier **118**, detector **119** and loudspeaker **120**.

The high frequency flux path in FIGURE 6 is partly in air. The signal flux path preferably includes saturating strip **121** between the lower ends of the core pieces. The thin saturating strip is preferably secured to a non-magnetic backing member **122**.

FIGURES 7 and 8 illustrate a head which may also involve high frequency flux paths through air wherein pole shoes **130** and **131** are mounted on brass backbone pieces **132** and **133** which may be clamped together with a suitable gap spacer **134** therebetween to define the non-magnetic gap. The pieces **132** and **133** may be secured, for example, by inserting cement in the space **136** therebetween. The pieces **132** and **133** are recessed to receive the coils **140** and **141** which may be arranged and excited as indicated in FIGURES 4 and 6. The saturating strips **143** and **144** may be secured in low reluctance relation to pole shoes **130** and **131** by means of plates **146** and **147** which in turn may be cemented in place. At the lower end, the magnetic circuit may be completed by a pair of yokes **150** and **151** which may also be cemented in place on the backbone **132**, **133**.

By way of example each coil may comprise 20 turns of No. 30 HF wound bifilar in two layers on a $\frac{1}{32}$ inch diameter form. The gap spacer may be a .0002 inch mica, the pole shoes may be .006 by $\frac{3}{32}$ inch "Mumetal" and the saturation strips may be .001 by $\frac{1}{32}$ by $\frac{1}{2}$ inch "Molypermalloy."

FIGURES 9 and 10 illustrate a magnetic modulator head utilizing a single saturating strip **180** completing a magnetic circuit with pole shoes **181** and **182** and non-magnetic gap **183**. The pole shoes may be soldered together as indicated at **184** and the saturating strip **180** may be clamped with turned-in portions **181***a* and **182***a* of the pole shoes by means of plates **186** and **187**. An inner winding **190** is connected to an oscillator **191** by means of leads **192** and **193** and provides high frequency fields due to the oppositely wound portions **190***a* and **190***b* thereof as indicated in FIGURE 10. The signal pickup winding **194** has leads **195** and **196** connected to amplifier **197** tuned to the second harmonic of the oscillator frequency, detector **198** which may be a conventional amplitude modulation detector such as found in radio circuits, power amplifier **198'** and loudspeaker **199**. The detectors of FIGURES 5 and 6 as well as FIGURES 12 to 15 and 17 may, of course, include power amplification stages if necessary. Bias flux greater than the maximum signal flux may be provided by battery **200**. This head construction has the advantage of providing oppositely directed high frequency fluxes at the gap **183** while requiring only a single saturating strip for ease of assembly.

By way of example the inner high frequency winding **190** may comprise 30 turns of No. 33 HF, 15 right hand turns and 15 left hand turns in one layer and have an inside diameter of $\frac{1}{32}$ of an inch, while the signal coil may comprise 30 turns No. 33 HF all in the same direction in two layers with an inside diameter of $\frac{3}{32}$ of an inch. The oscillator coil may be $\frac{9}{32}$ of an inch long while the signal coil may be $\frac{9}{64}$ of an inch long. The single modulator strip may advantageously be .001 by $\frac{1}{32}$ inch.

FIGURE 11 illustrates a head construction similar in operation to that of FIGURES 9 and 10 wherein a signal coil **194'** is connected in a circuit as shown in FIGURE 10 and is wound around a high frequency coil (not shown) which is wound part in one direction and part in the opposite direction as the winding **190** in FIGURES 9 and 10 and is energized as the winding **190** in FIGURE 10. The saturating member **201** is of reduced cross-section as in the previous embodiments. The pole shoes **203** and **204** define a non-magnetic gap **205** and are in magnetic circuit with the saturating strip **201** by means of core portions **207**—**210**.

FIGURE 12 illustrates a head construction utilizing a single winding **220** all wound in the same direction on a saturating strip **221** bridging between a pair of pole pieces **222** and **223** defining a non-magnetic gap **224**. The winding **220** is excited by means of an oscillator **225** through capacitance **226** and inductance **227** tuned to the fundamental frequency of oscillator **225**. The output is taken from the winding **220** through an amplifier **229** tuned to twice the frequency of the oscillator **225**, a suitable detector **230** and output device **231**. Polarizing flux is introduced by means of battery **233** and resistor **234**. It will be observed that the saturating strip **221** may have enlarged portions **221***a* engaging flatwise with the lower faces of the poles **222** and **223** to provide a complete loop magnetic circuit. This head construction has the disadvantage that the fundamental frequency component from the oscillator is not balanced out at the gap, so that the high frequency excitation must be adjusted to a value too low to cause erasure of the signal on record member **235**. In practice, with a thin saturating strip portion **221***b*, it has been found substantially impossible to produce an appreciable erase field at gap **224**.

It may be noted that in magnetic circuits where the saturating strips are in series, the strips may be twice as wide as where the strips are in parallel, providing a definite mechanical advantage in handling the fabrication of the strips. This is the result of the fact that all of the flux from the record member passes through each of the saturating strips. It may also be noted that with the embodiment of FIGURES 9 and 10, there is the advantage that the two winding portions **190***a* and **190***b* may be formed from the same electrical conductor thereby avoiding the necessity for interconnecting two windings in series or parallel.

While the windings have been described as being energized by alternating electrical energy, other suitable excitation energy may be employed with corresponding modifications in the electrical output means for deriving an electrical signal from the resultant flux variation in the head.

Referring now to FIGURE 13, a further embodiment has been illustrated wherein a magnetized record member **250** travels across pole shoes **251** and **252** at the non-magnetic gap **253** therebetween, and the pole shoes have a thin saturating strip **256** with enlarged end portions **256***a* in flatwise engagement with the inturned ends of the pole shoes and a reduced cross section central portion **256***b* of similar outline to that shown at **221** in FIGURE 12. The thin saturating strip may be carried by a suitable non-magnetic support **257** of corresponding configuration and may be secured thereto as by a suitable cement for ease in handling of the saturating strip. Polarizing flux may be introduced by a very weak magnet such as indicated at **259** which in practice may comprise a magnetized piece of magnetic recording tape less than a quarter inch in width. The required value of polarizing flux has been found insufficient to affect the tape **250** at the gap **253**. As previously described, the polarizing flux in the saturating strip is preferably greater than the maximum signal flux produced in the saturating strip by the record member **250**. This same relationship holds true for the embodiments of FIGURES 1 to 12.

It will be observed in FIGURE 13 that the high frequency excitation is supplied from an oscillator **260** through condenser **261** and inductance **262** tuned to the fundamental frequency of the oscillator **260**. The windings on the saturating strip are bifilar wound with one winding portion **264** connected in series with an inductance **265** and the high frequency oscillator **260**, while the other bifilar winding portion **267** is connected in series with an inductance **268** and the input terminals of an amplifier **269** preferably tuned to an even order harmonic of the fundamental of oscillator **260**. The output of the tuned amplifier **269** is fed through detector **270** to the output device **271** which may be a loud speaker. The inductances **265** and **268** are coupled in such a way as to balance out the fundamental component induced in the output winding **267**, so that with no signal introduced at the gap **253**, there will be no fundamental frequency component in the input circuit of tuned amplifier **269** including coils **267** and **268**. It will be understood that as a signal flux is introduced into the saturating strip **256**, the fundamental component in the input circuit to tuned amplifier **269** will be unbalanced and there will be a fundamental frequency component in the output circuit reflecting the signal on the tape **250**. Thus, the amplifier **269** could be tuned to the fundamental frequency to obtain an output signal. However, tuning to the second harmonic of the oscillator frequency is preferred.

FIGURE 14 illustrates a ring type core **300** having a non-magnetic gap **301** for receiving a record medium **302** thereacross which is designed to operate without the use of a reduced cross-section saturating portion. In this embodiment, the core is preferably of relatively large cross-section and preferably of a magnetic material having a relatively linear B-H characteristic, such as "Conpernik" having a composition of 50% nickel and the remainder iron and minor constitutents, or "Perminvar" having a composition of 25% cobalt, 45% nickel and the remainder iron and minor constituents. Further, in this embodiment, the high frequency windings 304 and 305 are preferably connected in series aiding relation with respect to the gap 301 so as to actually excite the magnetic material of the record member 302. The high frequency magnetic intensity at the gap 301 is preferably of a small amplitude in comparison with the coercive force of the record member. With such excitation, the magnetic material of the record member operates on a minor hysteresis loop, the incremental permeability of which depends on the residual magnetization of the portion of the record member at the gap 301.

In this embodiment it will be apparent that the head responds not to the external leakage flux from the record member, but to the actual internal magnetization of the record member. The signal flux acting on the head is thus independent of the recorded wave length of the signal so that a fundamental defect of heads relying on leakage flux from a record member is overcome. Signal pickup windings 310 and 311 may be bifilar wound with windings 304 and 305 respectively, and also in series aiding relation with respect to the gap 301. The oscillator circuit is provided with an inductance 312 and the pickup circuit is provided with an inductance 313 coupled therewith, so that the coupling between inductances 312 and 313 may be varied to balance out the fundamental component in the pickup circuit in the absence of a signal flux from the tape 302. Polarizing flux may be introduced by means of a magnet 315. An amplifier 316 has its input connected to the pickup circuit and is preferably tuned to an even order harmonic of the frequency of the oscillator 317. The output of the tuned amplifier 316 is connected through a conventional amplitude modulation detector and power amplifier unit 318 to an output device 319 such as a loud speaker.

In FIGURE 15, a magnetic head is illustrated having a pair of pole shoes 320 and 321 defining a non-magnetic gap 322 receiving a record member 323 thereacross. A relatively thin flat member 325 of magnetic material bridges across the pole shoes 320 and 321 and is disposed in flatwise engagement with the ends of the pole shoes 320 and 321. The member 325 may have a window 325*a* therein to define a pair of thin saturating strips 325*b* and 325*c*. A magnet 327 is illustrated as applying polarizing flux to the strips 325*b* and 325*c*, the magnet being too weak to affect the record member 323. In this embodiment, windings 330 and 331 are excited by means of fluctuating electrical energy in the form of a series of unidirectional rectangular pulses such as indicated schematically at 334 from a pulse generator 335. The windings 330 and 331 are preferably connected in series opposing relation with respect to the gap 322 so that there will be no net exciting flux at the gap. Pickup winding 338 and 339 may be connected in aiding relation with respect to the gap 322 and be connected through an integrating circuit such as resistance 340 and capacitance 341 to a detector 342 and output device such as a meter 343. It will be understood that pulse operation of the head makes possible multiplex operation wherein a multiplicity of channels may be successively scanned by means of successive pulses to successive heads so as to reproduce a signal distributed across a multiplicity of channels. In this instance, each head would be pulsed at intervals as shown in FIGURE 15. In the illustrated embodiment, the output at 343 would consist of a series of pulses at the frequency of pulses 334 and varying in amplitude and polarity in accordance with the signal on the record member 323.

FIGURES 16 and 17 illustrate one manner in which a saturating strip 360 may be excited without winding a conductor continuously therearound in a helix as illustrated in the preceding embodiments. In this case, as illustrated in FIGURE 16, a conductor 361 is wound in one or more layers as illustrated with successive parallel portions 361*a*, 361*b*, 361*c*, 361*d* and 361*e*. The winding 361 is then folded on a median plane indicated by the dot-dash line 363, and the saturating strip 360 slipped into the folded winding as illustrated in FIGURE 17. It will be observed in this embodiment that the conductor portions 361*a*, 361*c* and 361*e* on each side of the strip 360 will induce flux in one direction longitudinally of the strip 360, while the conductor portions 361*b* and 361*d* will induce fluxes in the opposite direction on both sides of the strip.

FIGURES 18 and 19 illustrate a further way in which a saturating strip 360 may be excited. Here, a conductor 366 is wound in a sinuous manner with successive parallel portions 366*a*, 366*b*, 366*c*, 366*d*, 366*e* and 366*f*. The winding is then folded on a median line 368 to receive the saturating strip 360 as indicated in FIGURE 19. In this embodiment, it will be observed that the conductor portions 366*a*, 366*c* and 366*e* on each side of the strip 360 induce magnetic fluxes in one direction while the alternate conductor portions 366*b*, 366*d* and 366*f* induce magnetic fluxes in the opposite direction.

It will be understood that in both FIGURES 17 and 19, the pickup windings can be wound on pole shoes such as 380 and 381 in FIGURE 17. Specifically, windings 382*a* and 382*b* may be provided connected in series aiding relation with respect to gap 383, the output being fed to a tuned amplifier and detector unit 384 and then to a loud speaker 385 as in previous embodiments. In this case, the head may also be conveniently utilized as a recording head, the windings 382*a* and 382*b* being connected with a suitable input 388 by means of a switch 389 to record on an unmagnetized record member 390. It will be understood that the pole shoes 380 and 381 must be of sufficient cross-section to carry the required recording flux.

As previously, the saturating strip 360 is preferably of greatly reduced cross-section in relation to the cross-section of the pole shoes 380 and 381. The total cross-section of the saturating strip 360 is required to be a fraction of the cross-section of the record-playback pole pieces 380 and 381. It may be noted that placing the windings 382*a* and *b* on the pole shoes rather than on the saturating strip results in an appreciable reduction in output voltage; however, with suitable operating conditions, the output is still superior to that obtained with that of induction type heads responding to the rate of change of signal flux. The record-playback head of FIGURE 17 is responsive directly to the signal flux at the gap 383 to give greatly improved low frequency response characteristics to the head and thus avoiding the need for low frequency equalization as required with an induction type head. Further, the output level is such as to avoid the need for a high gain amplifier which tends to introduce hum and other noise into the output.

FIGURE 20 illustrates the relation of output to the applied intensity of the magnetic field established in the saturating strips. This relationship is applicable to the embodiments of FIGURES 1 to 13 and 17. Curves 400 and 401 illustrate the signal and noise output in decibels (on different scales) while curve 403 is a plot of signal minus noise in decibles as a function of the intensity of the magnetic field established by the oscillator in the saturating strip. Point 404 on curve 403 may correspond to a signal minus noise value of 68 decibels. Point 405 may correspond to a signal minus noise value of 76 decibels. The vertical line 408 may correspond to the intensity of the magnetic field in the saturating strip just producing the saturation value of intrinsic induction in the strip. It will thus be observed that optimum signal-to-noise ratio is obtained by driving the oscillator to produce values of magnetic intensity in the region of or preferably above the saturation value of magnetic intensity for the saturation strips. It will be understood from FIGURE 20 that the maximum value of H due to the oscillator excitation is preferably greater than the maximum H provided by the polarizing source and the signal magnetization in the saturating strip. Specifically the relationships illustrated in FIGURE 20 were obtained using a head configuration with two saturating strips in parallel having a total cross section of about 62 square mils and made of "Molybdenum Permalloy," the head gap **322** being of extent to receive a one-quarter inch tape.

With reference to the embodiments of FIGURES 1 through 13, 15 and 17, it has been found that for useful reproduction of music, with optimum amplitude of high frequency excitation as disclosed herein, the total cross-sectional area of the saturating strip or strips in each of these embodiments must be less than about

$$\frac{50(B_tA_t+P+F)}{B_s}$$

where B_t is the maximum residual induction of the record member, A_t is the cross-sectional area of the magnetized portion of the record member, P is the polarizing flux in the saturating strip, F is any feed back flux which may be introduced into the saturating strip, and B_s is the intrinsic saturation induction for the saturating strip, the valves being taken in consistent units. This limit of about

$$\frac{50(B_tA_t+P+F)}{B_s}$$

is the approximate maximum limit for useful reproduction of music since musical reproduction with cross sections appreciably above this limit produces a result which is usually unacceptable to the listener and to this extent represents the critical limit for useful reproduction.

Feedback is illustrated in FIGURE 4 as being taken at the output of a stage of amplification indicated at **420** and prior to a further stage of amplification **420'** by means of a capacitance **421** and resistance **422** coupled to signal windings **29*b*** and **30*b*** by leads **43** and **44**. With one polarity of the battery **50**, the feedback will be negative, while with the other polarity of the battery **50**, the feedback will be positive. It will be observed from the above formula that with positive feedback, and for a given signal-to-noise ratio, the maximum permissable area of the saturating strips is increased, while with negative feedback, the maximum permissable cross section is reduced. It has been found that the use of negative or inverse feedback is an effective way of improving the linearity, reliability, and stability of the heads of the present invention. With a sufficiently high feedback factor, all distortion and gain variations, except those in the tape recording itself and effects due to varying degree of contact between the tape and playback head, can be reduced to negligibly small effects. It was found that with the proper value of the feedback components, the net output signal from a constant level recording on tape was essentially unchanged in spite of artificially produced large changes in the gain of the amplifier.

For each of the embodiments of FIGURES 1 to 13, 15 and 17, the polarizing flux is preferably of magnitude greater than the maximum signal flux in the saturating strips.

For a useful signal-to-noise ratio for reproduction of music, it has been found that the area of the saturating strips must be less than 15 times the cross-sectional area of the magnetizable portion of the record tape where a polarizing flux is present and tape has a maximum flux capacity of approximately 1 maxwell. This limit is reduced by a factor of two where there is no polarizing flux and is reduced proportionately if the residual flux capacity of the tape is less than one maxwell, or increased proportionately if the flux capacity is greater than one maxwell. For example, for a flux capacity of .5 maxwell, the limit would be 7½ times the cross-sectional area of the magnetizable portion of the tape.

It has been found that for fine scanning of the record member, a small gap is required. This in turn tends to reduce the amount of flux linking the head and to require a relatively small saturating strip. With relatively small signal flux linking the saturating strip, it is advantageous to use a high frequency excitation in the saturating strip. However, core losses are not prohibitive at the high frequencies because of the small dimensions of the saturating strips. The present invention thus makes feasible a very fine scanning gap while providing the required high output level for a good signal-to-noise ratio.

It may be noted that negative feedback reduces the effective signal flux in the saturating strips, and thus allows for a further reduction in the minimum size of the strips for distortionless output. On the other hand, a positive feedback increases the permissible maximum size of the strips by effectively adding to the signal flux.

The following modifications in the illustrative embodiments may be noted by way of example. In FIGURE *5a*, a single loop conductor may excite the core rather than a multiplicity of turns. Further, a conductor carrying current of one phase may extend on one side of the core, and a conductor carrying current of the opposite phase may extend on the other side of the core to excite the core with bucking high frequency excitation with respect to the gap without actually wrapping a conductor completely around the lower saturating strip portions. It will be understood that the windings **140** and **141** of FIGURE 7 may be excited in the manner illustrated in FIGURE 4, and the output taken by means of the circuit shown in FIGURE 4. In FIGURE 6, the saturating strip **121** may be omitted to leave a gap across the lower portion of the core, and the head will operate, although unless the legs of the pole pieces **100** and **101** are of relatively small cross-section, the resulting noise level will make the head unusable for the playback of music signals. The oscillator coils are preferably linked to the pole legs at regions relatively remote from the gap, so as to avoid the possibility of erasing effects upon the tape due to the high frequency excitation flux generated by the coils.

It may be noted that in the embodiments of FIGURES 1 through 14 and 17, the oscillator excitation may be tuned to a frequency of 500 kilocycles per second, for example, and the output of the pickup coil may be delivered to a conventional radio set tuned to 1 megacycle per second. In such a case, polarizing flux is most conveniently supplied by means of a permanent magnet arrangement such as illustrated in FIGURE 13 or 14. With one arrangement utilizing thin cross section saturating strips such as disclosed herein it was found that the noise from the head was definitely below that of the tape itself. It was also found that optimum performance in the playback system corresponded to a considerably higher oscillator input to the head than would be expected, and in fact some heating of the head occurred at the optimum value of oscillator input. However, the required power is obtained from the miniature 12AU7 oscillator tube without difficulty and no erasure of the tape was found.

It will be understood that the heads illustrated in the drawings may be used for recording transversely of the tape, for example, with the gap at an angle other than a right angle to the path of travel of the tape or even parallel to the path of travel of the tape.

Further, the pole pieces may be offset parallel to the long dimension of the gap to provide closely abutting parallel gap surfaces which overlap for only a fraction of the total extent of the respective gap surfaces. For example, with gap surfaces **425** and **426** offset laterally of the tape **427** as shown in FIGURE 21, and extending at right angles to the direction of travel of the tape as indicated by arrow **428**, a short wavelength recorded signal will be concentrated in a longitudinally recorded field at the central portion of the tape which travels across the longitudinally spaced overlapping portions **425*a*** and **426*a*** of the gap surfaces of the poles. However, for long wavelength recording, diagonal magnetization of the outer portions of the tape **427** will occur for example between the exposed gap surface **426*b*** of one pole and a side surface **425*c*** of the opposite pole, which side surface may, for example, extend parallel to the direction of the tape travel. The overlapping portions **425*a*** and **426*a*** may have a length between zero and several gap widths. This off-set shoe construction in the head results in response to infinitely long wavelengths as well as good short wavelength resolution.

As indicated in FIGURE 5*a*, a pair of core pieces **500, 501** of magnetic material may be glued, cemented or otherwise bonded to the pole portions of the "I" lamination so as to enlarge the tape contacting area of the head and improve the long wavelength characteristics thereof. The additional core pieces may be made of a suitable ferrite material which may be a homogeneous crystalline material composed of ferric-oxide and the oxide of another metal.

The embodiment of FIGURE 15 may be utilized in an electronic organ. In this application the pulsed head acts as a frequency changing device which reproduces the waveform of a recorded repeating signal at any desired frequency. With this system, there is required for each pitch of the organ a pulse generator, and a magnetic drum with recorded wave form is required for each stop of the organ. Thus, an organ with 73 pitches and 20 stops would have 73 pulse generators and 20 magnetic drums, a total of 93 basic elements replacing the 1460 pipes of an equivalent pipe organ.

With respect to the embodiment of FIGURE 13, the modulator strip **256** is cut to shape with the wide end portions annealed flat, and then cemented to a Bakelite stiffening piece such as indicated at **257**. The coils are then wound on the strip assembly. With this construction procedure there is a minimum possibility of straining or otherwise damaging the modulator strips.

It will be apparent that many further modifications and variations may be effected without departing from the scope of the novel concepts of the present invention.

I claim as my invention:

1. A magnetic transducer device comprising a magnetic core providing a single magnetic path, the core being adapted to receive flux from an external source linking said path, means including winding means for generating opposed exciting fluxes in said magnetic path, a strip of reduced cross-section forming at least a portion of said magnetic path, and said winding means being provided by a single conductor having portions oppositely wound on said strip, and signal winding means linking the portion of said strip on which said conductor is wound in radially offset relation.

2. Magnetic apparatus comprising magnetic core means providing a loop magnetic flux path, means for introducing a signal flux into said loop path, said path including an elongated strip of magnetic material of relatively small cross section in comparison to the cross section of other portions of said core means, means comprising exciting windings on said strip for producing opposed exciting fluxes in said strip, and output means on said strip and separate from said exciting windings and coupled to said exciting fluxes for producing an electrical output.

3. Magnetic apparatus comprising magnetic core means providing a loop magnetic flux path, means in series in said loop magnetic flux path for introducing a signal flux into said loop path, said path including an elongated strip of magnetic material of relatively small cross section in comparison to the cross section of other portions of said core means, means comprising exciting windings on said strip for producing opposed exciting fluxes in said strip, and means coupled to said exciting fluxes for producing an electrical output, said last-mentioned means comprising a pickup winding on said strip.

4. Magnetic apparatus comprising a magnetic core providing a series magnetic path and including means for introducing a signal flux in said path, said core including a portion which saturates at a lower value of flux than other portions of said core, exciting winding means on said portion for generating oppositely directed exciting fluxes at sections of said portion offset along said path, and an output winding encircling said portion in overlapping relation to said exciting means.

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