A new pick-up (type AG 3020/21) working on the magnetodynamic principle, has recently been marketed and has been the subject of two articles in this journal. It may be recalled that this pick-up employs a ferroxdure magnet in the form of a thin rod, magnetized at right-angles to its axis and mounted so as to be able to rotate about its axis, between the ends of a magnetically conducting yoke carrying two coils. The vibrations of the needle are converted, via a lever (the needle arm), into a turning movement of the magnet about its axis. This movement sets up an alternating flux in the yoke, which induces an alternating voltage in the coils.

The magnetodynamic pick-up is of such a quality that it can compete with electrodynamic pick-ups, which have hitherto generally been used for professional purposes. On the other hand its price is not so high as to prohibit its use in non-professional record players. In the latter case the pick-up will often be used in conjunction with a radio set, as is commonly the case with piezo-electric pick-ups. There are, however, two reasons why direct connection of the magnetodynamic pickup to an ordinary radio would not give satisfactory results. Firstly, it is less sensitive, so that an extra amplification stage is necessary. Secondly, the voltage delivered is proportional not to the amplitude, as in the case of the piezo-electric pick-up, but to the velocity of the needle point. This difference necessitates an electrical correction, which can be applied in the extra amplification stage.

Some correction is necessary even with the piezo-electric pick-up. Often this is nothing more than a very rough correction by means of mechanical resonances in the pick-up system. The better pick-ups, such as the type AG 3015 piezo-electric pick-up and the magnetodynamic pick-up, demand a more accurate correction, which it is practically impossible to obtain otherwise than electrically.

It is desirable that the extra amplification stage (pre-amplifier incorporating correction devices) be easily interposed between the magnetodynamic pick-up and a normal radio; it should therefore preferably be small and unobtrusive. Still more important, it should include its own supply unit, in order to avoid the complication of drawing the supply from the radio.

Adequate amplification could easily be attained with one valve, e.g. a double triode, but transistors are much more convenient for the present purpose: they are smaller than valves, have no filament, and require less D.C. power. This power can then easily be supplied by the mains via a germanium diode, which compared with a rectifying valve has the same advantages which transistors have over amplifying valves, viz. it is smaller in size and has no filament.

One transistor is found to be adequate. The complete circuit — the signal current and direct current parts of which will be examined separately later in the article — is shown in fig. 1. It will be observed that the transistor T is used in the circuit with a common emitter, in which the base forms the input electrode and the collector the output electrode. The pre-amplifier (type AG 9005) in its box, is shown in fig. 2.

![Fig. 1. Circuit of the pre-amplifier type AG 9005. The input terminals I are connected to a magnetodynamic pick-up AG 3020 or AG 3021, the output terminals II to the pick-up terminals of a radio set. T junction transistor OC 73. Tf supply transformer. D germanium diode OA 81. C1, C2, C3 decoupling capacitors. C4 coupling capacitor. For the significance of the other letters, see fig. 4 and fig. 6.](https://example.com/fig1.png)
Fig. 2. External appearance of the pre-amplifier (with power unit) type AG 9005. Approximate dimensions: base $3^{1/2} \times 3''$, height $2''$.

Frequency characteristic

For most gramophone records the recording curve is of the type shown by $B$ in fig. 3. This "New Orthophonic" curve, as it is called, gives the peak stylus velocity $\nu$ with which the groove is cut in the lacquer disc during recording \(^2\) as a function of the frequency $f$ on a logarithmic scale. $B$ is the mirror image of the "standard response" curve $A$ with respect to the level at 1 kc/s; the "standard response" curve gives the output voltage $E$ as a function of $f$ of a certain reproducing channel proposed as a standard for gramophone reproduction, the needle point of the pick-up having a constant peak velocity. With the magnetodynamic pick-up, the induced e.m.f. is proportional to the velocity of the needle point and thus (if the pick-up is assumed to be perfect) to the velocity of the cutting stylus. The amplifier used with the magnetodynamic pick-up must, therefore, have a frequency characteristic which approximates as closely as possible to the standard response curve $A$. In the case in question, it is the characteristic of the pre-amplifier which must conform to the curve $A$, since the remaining part of the reproduction channel (i.e. the low-frequency section of the radio) is designed for signals which are independent of the frequency. Frequencies above 1 kc/s must therefore be amplified by the pre-amplifier to a lesser extent than the frequencies below 1 kc/s.

A good approximation to the desired characteristic has been obtained by means of two provisions: 1) a negative feedback link $R_5$-$C_5$ between the collector and the base, and 2) a resistor $R_8$ in series with the pick-up (see fig. 4, which shows only the signal current section of fig. 1; the pick-up is now represented as a generator of e.m.f. $E_i$, self-induction $L_i$ and internal resistance $R_i$).

To illustrate the effect of these measures, consider now in fig. 3 the schematic curve $A'$ in place of the standard response $A$. This exhibits an amplification which decreases inversely with the frequency up to 0.5 kc/s and again above 2.1 kc/s, and is constant between these two frequencies.

At frequencies $f = \omega/2\pi$ such that $1/\omega C_5 \ll R_5$, the link $R_8$-$C_5$ produces a negative feedback which is (virtually) independent of $f$, so that in this range the amplification (apart from other effects) is independent of $f$. At low frequencies, when $1/\omega C_5 \gg R_5$, on the other hand, the negative feedback increases in direct proportion to $f$, and consequently the amplification decreases approximately inversely with $f$, just as required by the left-hand side of the schematic response curve $A'$. The transition from the one frequency range to the other is characterized

by the frequency \( f_1 = 1/(2\pi R_6 C_6) \). The values of \( R_6 \) and \( C_6 \) are chosen in accordance with the response curve so that \( f_1 \) is about 0.5 kc/s.

The combination of inductance and resistance in the circuit comprising \( L_i \), \( R_i \), \( R_6 \) and the base-emitter resistance \( R_{be} \) has just the opposite effect. The alternating current in the base is proportional to \( f_2 \), the base-emitter resistance \( R_{be} \) lies at 2.1 kc/s. The resistance \( R_6 \) and is (almost) inversely proportional to \( f \) for \( f \gg f_2 \). If we now plot the logarithm of the base current against \( f_2 \), we find therefore a horizontal line for \( f \ll f_2 \), and a falling straight line above this frequency, corresponding to the right-hand part of the response curve. The transition frequency lies at 2.1 kc/s. The resistance \( R_6 \) is so chosen that \( f_2 \) has this value.

The result of both the above measures combined is shown in fig. 5, where the output voltage \( E_o \) of the pre-amplifier is plotted as a function of \( f \), the input voltage \( E_i \) varying with \( f \) in accordance with the characteristic \( B \) in fig. 2. External load 150 k\Omega.

Fig. 5. Output voltage \( E_o \) on a logarithmic scale as a function of the frequency \( f \), \( E_i \) varying with \( f \) in accordance with the characteristic \( B \) in fig. 2. External load 150 k\Omega.

Data concerning sensitivity, amplification and distortion of the pre-amplifier in combination with the magnetodynamic pick-up are given in the table below. Certain quantities quoted in the table may be usefully defined here.

Table. Sensitivity, amplification and distortion data on the pick-up AG 3020/21 with the pre-amplifier AG 9005. External load: resistance \( \geq 120 \) k\Omega in parallel with a capacitance of \( \leq 10^{-6} \) F.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>60 c/s</th>
<th>1000 c/s</th>
<th>10 000 c/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
<td>400</td>
<td>71.5</td>
<td>15.5</td>
</tr>
<tr>
<td>Voltage amplification</td>
<td>41</td>
<td>27</td>
<td>25</td>
</tr>
<tr>
<td>Current amplification</td>
<td>21.4</td>
<td>7.8</td>
<td>5.2</td>
</tr>
<tr>
<td>Insertion gain</td>
<td>41</td>
<td>25</td>
<td>13.6</td>
</tr>
<tr>
<td>Transfer impedance</td>
<td>1170</td>
<td>230</td>
<td>180</td>
</tr>
<tr>
<td>Distortion (for maximum ( E_o ) and an ambient temperature of 20 °C)</td>
<td>( \leq 1.5 )</td>
<td>( \leq 0.4 )</td>
<td>( \leq 2 ) %</td>
</tr>
</tbody>
</table>

Sensitivity: output voltage \( E_o \) (r.m.s. value) in mV for a peak needle velocity of 1 cm/sec.

Voltage amplification: 20 log \( E_o/E_i \) dB.

Current amplification: 20 log \( I_o/I_i \) dB (\( I_i \) = input current, \( I_o \) = output current).

Insertion gain: 20 log \( E_o/E_i \) dB, where \( E_i \) is the terminal voltage of the pick-up when the latter is loaded with its normal load resistance (68 k\Omega).

Transfer impedance: \( E_o/I_i \), in mV/\muA.

Stabilization of the working point

At maximum modulation the output voltage may show peak values of 3.5 V. To avoid distortion it is necessary to ensure that the D.C. voltage \(|V_{cc}| \) between collector and emitter never falls below 4V. \(|V_{cc}| \) is given the rather high nominal value of 10 V, but for a number of reasons the danger that \(|V_{cc}| \) might become less than 4 V is a real one: not only must mains voltage fluctuations be taken into account, but also the quite appreciable effect of the temperature, the spread in the properties of transistors and the spread in resistance values.

A new type of junction transistor \(^3\) has been selected, OC 73, which has been found during manufacture to have an appreciably smaller spread in properties than the older types. Resistors with a tolerance of \( \pm 2\% \) have been specified where the accurate value of the resistance is critical.

The effect of the temperature still remains. In general, temperature has quite an appreciable effect on transistors, and the pick-up preamplifier is required to work well for all ambient temperatures, from 10 to 45 °C (this higher temperature limit is stipulated since it is anticipated that the magnetodynamic pick-up will find a ready market in the tropics as it is better able to withstand tropical conditions than are other systems).

As a first step towards minimizing the effect of temperature a resistor \( R_7 \) is connected in series with the common electrode — in this case the emitter (see fig. 6, which shows the direct current part of the circuit in fig. 1). Just as a cathode resistor has a stabilizing action on the anode current of valves, so here \( R_7 \) (shunted by capacitors \( C_3 \) and \( C_4 \) in series, see fig. 1) has a stabilizing effect on the collector D.C. (D.C. negative feedback), and consequently on the voltage \( V_{ce} \).

This single precaution is not enough however. In order to obtain high amplification, a high value has been chosen for the collector resistance \( R_6 \) (0.1 M\Omega). Hence a slight increase in the collector

current (as a result of an increase in temperature) may be sufficient to cause $|V_{ce}|$ to fall below the admissible value. For this reason, as a second stabilizing device, a thermistor (NTC resistor) $R_a$ with a large negative temperature coefficient has been incorporated in the potential divider $R_s + (R_a/R_b)$ which determines the potential of the base. As a result the potential of the base is dependent on the ambient temperature in such a way that the effect of the temperature on the transistor is adequately compensated.

This compensation can be explained as follows. In fig. 7, a indicates the value at which it would be desirable to keep $|V_{ce}|$ constant (10 V). If there were no thermistor, $|V_{ce}|$ would depend upon the ambient temperature $T$ as shown by line $b$. If $R_{a}/R_b$ is replaced by a variable resistor and a graph is plotted of how resistance must vary to keep $|V_{ce}| = 10$ V as $T$ changes from 10 to 45 °C, the curve $R$ in fig. 8 is obtained. The variation of a thermistor with $T$ differs considerably from curve $R$, as shown by curve NTC. By connecting a thermistor in parallel with an ordinary resistor, a temperature variation like $R_{a}/R_b$ in fig. 8 can be obtained which can be made to approximate sufficiently closely to the desired variation ($R$). In the case in point this is achieved by connecting a thermistor of 47 kΩ (at 25 °C) in parallel with an ordinary resistor, of 20 kΩ. The extreme values of $|V_{ce}|$, found with this combination, all tolerances having been taken into consideration, are given by the curves $c$ and $d$ of fig. 7. It may be seen that in the temperature range from 10 to 45 °C, $|V_{ce}|$ never falls below 4 V and never exceeds 20 V (the maximum value which is permissible for the transistor).

Resistor $R_b$ (fig. 1 and fig. 6) ensures that the base circuit is not interrupted when the pick-up is being changed or disconnected and prevents too high a voltage from being applied to the transistor. The resistance of $R_b$ is so high (0.47 MΩ) that it has no effect when the pick-up is plugged in. It may be noted that the D.C. base current (maximum about 50 µA) flows through the pick-up, but is quite harmless.

**Power unit**

The high values of $|V_{ce}|$ (nominal 10 V) and of the collector resistor $R_e$ necessitate a relatively high supply voltage, namely 36 V. This voltage

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The pre-amplifier AG 9005 with cover removed. The cylindrical screening can houses the pre-amplifier proper (see fig. 10). Significance of the letters as in figs. 1, 4 and 6 can be obtained by rectification with a germanium diode 5) OA 81, the maximum peak inverse voltage of which is 115 V. With the current required here (about 0.4 mA) this diode is only carrying a fraction of its maximum permissible load.

The filter $C_1R_1C_2$ (fig. 1) smooths the rectified voltage to the extent that the extra hum produced in the loudspeaker when the pre-amplifier is switched in is barely audible. This means that the hum component in the output voltage of the pre-amplifier is less than 1.5 mV, i.e. about 65 dB below the maximum output voltage.

There is one point to be mentioned regarding the transformer. In conformity with safety requirements the supply transformers in radio sets, amplifiers, etc. are provided with a temperature-sensitive safety device which automatically cuts off the mains supply to the transformer if the latter threatens to become too hot. In the pre-amplifier under discussion, the transformer is so small that it would be difficult to fit such a safety device. Fortunately such a device is found to be unnecessary since the transformer is short-circuit proof. In normal operation the power dissipated mainly comprises iron losses. If the secondary coil is short-circuited the copper losses of course increase, but owing to the relatively large stray inductance and resistance of the coil the increase is only small. Moreover, owing to the increased voltage drop in the primary coil, the induced e.m.f. becomes smaller, and hence the iron losses decrease. Thus in the event of a short circuit the total loss changes hardly at all, so that the transformer does not become too hot.

**Mechanical construction**

The pre-amplifier complete with power unit is mounted in a rectangular “Philite” box (fig. 2 and fig. 9), of size $86 \times 78 \times 49$ mm (about $3\frac{1}{2}'' \times 3'' \times 2''$). The pre-amplifier proper is constructed as a self-contained unit, all its components being mounted on an insulating plate which is housed in a cylindrical screening can (fig. 10). The reason for this is that if future designs of radio sets and amplifiers should have the pre-amplifier power supply (36 V, 0.4 mA) already built-in, it will only be necessary to add the pre-amplifier proper as in fig. 10.

**Summary.** Description of the pre-amplifier AG 9005, designed for coupling the magnetodynamic pick-up AG 3020(21 to a normal radio. Its purpose is to amplify the signal voltage to an adequate level (max 2.5 V r.m.s.) and at the same time to provide a frequency characteristic conforming to the “New Orthophonic” cutting characteristic of gramophone records. The necessary amplification is obtained with one OC 73 transistor connected with common emitter. As one of the measures taken to stabilize the working point at differing ambient temperatures (10 to 45 °C), a thermistor is incorporated. The power unit contains a transformer, a germanium diode OA 81 and a smoothing filter. The pre-amplifier proper, together with supply unit, is mounted in a box about $3\frac{1}{2}'' \times 3'' \times 2''$. 

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