

# A New Wide-Range Phonograph Cartridge

JOHN F. WOOD\*

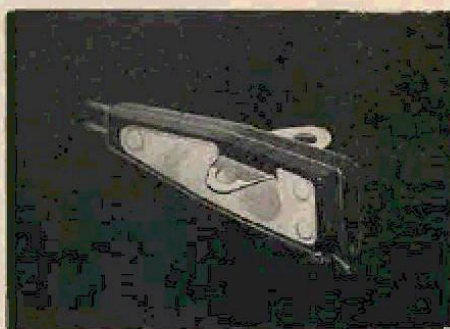
A description of the newest contender in the field of hi-fi reproduction. The principles of operation of the barium-titanate cartridge are outlined, and the economies of such a device are discussed.

FOR MANY YEARS the magnetic phonograph cartridge has been accepted as the standard of the industry and used in practically all professional and high quality reproducing systems. With specialized associated equipment, excellent response can be obtained over the major portion of the audio spectrum. While ideally suited for the constant velocity recording characteristic, there are definite disadvantages to the use of a velocity type of pickup on modern records. Until recently there has been little else available and the use of the magnetic cartridge has been accompanied with equalizing circuits and preamplifiers of increasing complexity.

With the development of the barium titanate piezoelectric element a new medium was available to the cartridge designer. Experience had been accumulated with the design and production of various ceramic cartridges for conventional phonograph use where high output and low cost were primary considerations. Accordingly, it was logical to pursue the development of a cartridge in which the full potentialities of the ceramic could be realized.

As the outgrowth of this program, the Electro-Voice Model 84 Ultra-Linear ceramic cartridge is presented to the music listener and professional as a cartridge eminently suited to the reproduction of modern records.

\*Senior Engineer, Electro-Voice, Inc., Buchanan, Michigan.



The new Electro-Voice Ultra-Linear ceramic pickup cartridge.

## Amplitude and Velocity

Unfortunately, a number of misconceptions have existed regarding cartridges and recording methods. In view of these misconceptions, a brief review of recording characteristics is desirable and follows in the paragraphs below.

Figures 1 and 2 are shown to clarify the relation between velocity and amplitude. The waveform is that of the record groove with frequency increasing toward the right. The frequency scale has been reduced because of limited space. According to the equation:

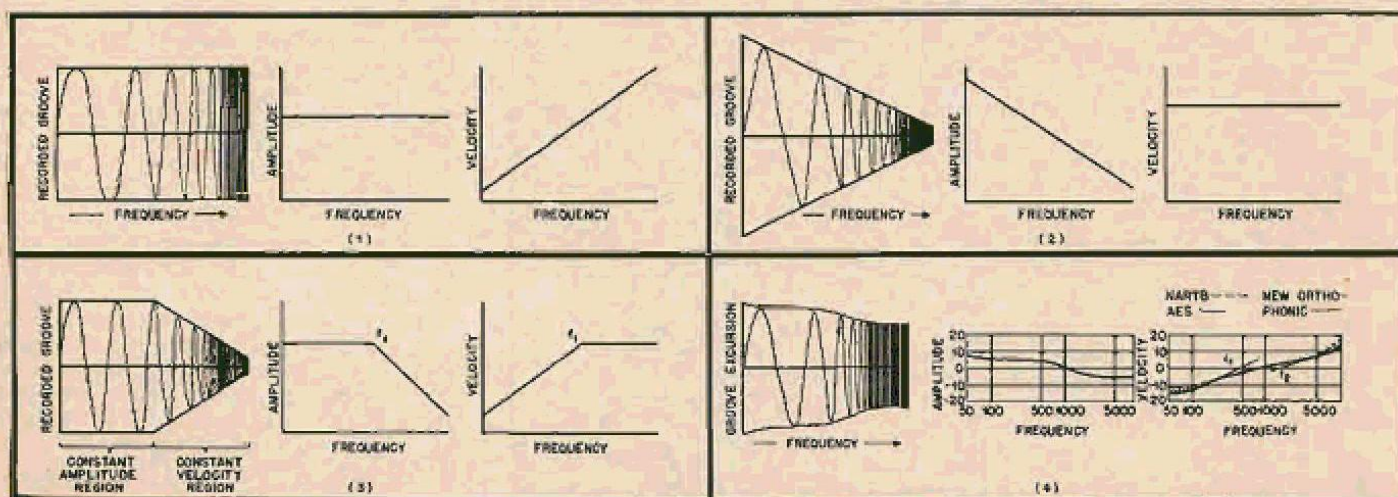
$$V = 2\pi fA$$

where  $V$  = velocity of a stylus moving laterally with the longitudinal motion of the groove,  
 $f$  = frequency  
 $A$  = amplitude of groove excursion,

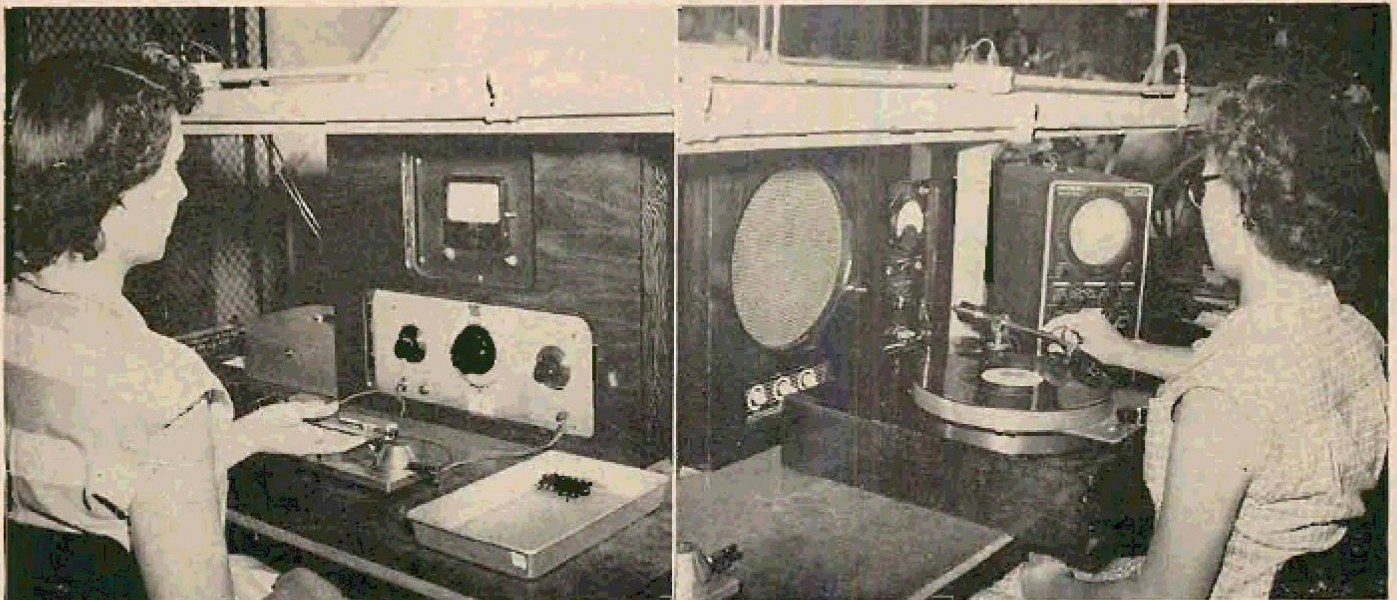
velocity will increase with frequency for a given amplitude at the rate of 6 db per octave. Conversely, amplitude will decrease with frequency for a given velocity at the rate of 6 db per octave. The statement is often made that a cartridge or system is "flat." To be accurate it is necessary to indicate the reference to constant amplitude, constant velocity, or some recording characteristic such as the New Orthophonic or National Association of Radio and Television Broadcasters recommended curves. For example, a velocity-flat cartridge would not reproduce a modern music record with an Orthophonic characteristic without considerable equalization.

## Origin of Recording Characteristics

The origin of constant-velocity recording goes far back into the history of sound recording. The old acoustic recording method, with elaborate horns and strong voiced artists, utilized essentially a velocity characteristic. The first electric cutters were of the magnetic type and recorded with a 6 db per octave descending slope on an amplitude basis. When played back with a magnetic pickup with the inherently inverse characteristic, the result was a flat reproduction of the original sound. Since the amplitude of the groove can become quite large at the lower frequencies, a reduction in level below some arbitrary crossover point was necessary to prevent the overcutting of one groove into the



Figs. 1 to 4. (1) Constant amplitude operation. (2) Constant velocity operation. (3) Standard frequency test record characteristic. (4) Modern recording characteristics.



(Left) Production testing of compliance, using a magnetically driven vibrating reed which is loaded by the stiffness of the cartridge. The change in amplitude of vibration is read from the meter which is calibrated directly in compliance—the reciprocal of stiffness. A high value of compliance is necessary to prevent distortion and actual damage to the record groove. (Right) Production testing of output voltage and frequency response. Voltage output at 1000 cps is indicated on the meter while playing a test record, and frequency response is checked within a 25 db envelope on the face of the oscilloscope over the range from 50 to 10,000 cps. The source for this test is a sweep-frequency record.

next. At this crossover point the transition was made electrically from constant velocity to constant amplitude. This characteristic is shown in *Fig. 3* and is still used for a number of standard frequency test records.

When interest was aroused in the more natural reproduction of sound, it was found that the signal-to-noise ratio was very poor. This was true because of the small groove amplitude at the higher frequencies. Consequently, high-frequency equalization was provided for the cutters in various degrees until, today, records are cut with very nearly a constant-amplitude characteristic. Variations from this characteristic exist for several reasons. The first reason is to facilitate design of equalizing networks. Another involves improvement in needle tracking at the high frequencies. Variations are often made by the recording engineer to compensate for acoustic deficiencies and to produce special effects.

The NARTB, AES and New Orthophonic characteristics are shown in *Fig. 4*. The crossover points still exist but do not have the significance of the old transition point. The lower point is shown at 500 cps ( $f_1$ ) and the upper point at 2120 cps ( $f_2$ ). Because of the gradual transition, the crossover can be defined as the intersection of the asymptote or tangent of the curve with the 1000 cps level.

Obviously, the correct reproduction of these curves requires compensation of any magnetic cartridge, whether it be variable reluctance, moving coil dynamic, or other. These cartridges operate in accordance with Faraday's Law:

$$e.m.f. = \frac{d\phi}{dt}$$

where *e.m.f.* = the generated electromotive force,  
 $N$  = the number of conductors in the field,

$$\frac{d\phi}{dt} = \text{the time rate of change of magnetic flux,}$$

For this reason this class of cartridges is referred to as the velocity type.

For the magnetic cartridges, equalization is usually accomplished by a rising gain in the preamplifier of about 6 db per octave below the lower crossover point. As the magnetic cartridge is inductive, high-frequency equalization can be accomplished by shunting with a load resistance of the proper value, as is done in some preamplifiers. In others this is done in other sections of the circuit.

The effects of this extensive reshaping of the response curve can now be considered. As mentioned above, the cartridge is inductive and is therefore susceptible to hum pickup from stray magnetic fields. These fields are produced by phonograph motors, transformers, and other electrical equipment. At 30-cps, the output of this cartridge is 18 db below the 1000-cps level, or from 1.25 mv to 5 mv in an average cartridge. Amplification of this low-level signal will increase the hum along with the signal. Furthermore, there is the consideration of tube and circuit noise which is always a problem in low level amplifier design.

#### The Barium Titanate Transducer

Barium titanate is a true ceramic material, similar to the material used in an ordinary tea cup. However, barium titanate possesses the unique ability to generate an electric charge when subjected to mechanical stress. This phenomenon is known as the piezoelectric effect. In such an element the generated e.m.f. is proportional to the mechanical strain in the material. Because of this phenomenon, pickups utilizing the piezoelectric effect are referred to as amplitude or displacement devices.

A typical element consists of two

slabs of barium titanate separated by an electrode surface which may be a metal strip or a deposit of silver. (See *Fig. 5*.) Electrodes are deposited on the outside surfaces and the entire assembly is charged by the application of a high voltage, just under the breakdown potential. This "charge" accomplishes an orientation of the molecular structure and produces piezoelectric sensitivity. A bending force applied to the element will stress one side in tension and the other in compression. The generated voltages of the two slabs are usually added in series to provide maximum output.

While the piezoelectric effect has been widely used in cartridges with Rochelle Salt or ammonium di-hydrogen phosphate (ADP) generating elements, certain characteristics limited their use for the conventional home phonograph. The higher output voltage of the Rochelle Salt element is offset by its susceptibility to damage by excess humidity and its dehydration by exposure to extreme dryness. Furthermore it dissolves in its water of crystallization at 130° F. ADP is better in these respects but has a much lower dielectric constant. On the other hand, the barium titanate element is completely resistant to moisture, is unaffected by temperatures up to and above 212° F., is relatively strong, and has a very high dielectric

(Continued on page 52)

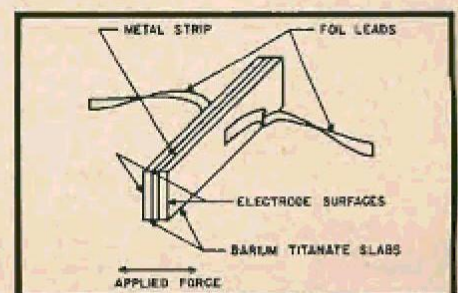


Fig. 5. A barium-titanate element.

# PHONOGRAPH CARTRIDGE

(from page 23)

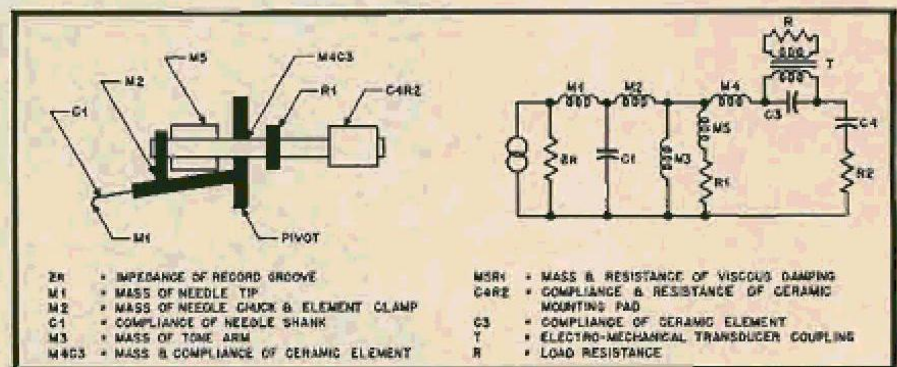


Fig. 6. Electro-mechanical equivalent circuit of a ceramic pickup cartridge.

constant. The sensitivity of this element, while somewhat lower than Rochelle Salt at 72° F., is of the same order of magnitude and does not ordinarily require changes in associated equipment.

In all piezoelectric materials, sensitivity and dielectric constant are dependent upon temperature. In a practical Rochelle Salt pickup, maximum output occurs at 72° F., and may temporarily drop to 60 per cent of this value at 90° F. The temperature output curve of barium titanate is relatively flat and the loss of sensitivity is negligible throughout temperature ranges encountered by any phono cartridge. Because of a dielectric constant four and one-half times greater than Rochelle Salt and an ultimate strength approximately five and one-half times greater, a practical titanate element can be much smaller in all dimensions. Accordingly, the effective mass of the element and associated drive mechanism is much less. Mass must be held to an absolute minimum to prevent excessive mechanical impedance from appearing at the needle with resulting distortion and increased wear on record and stylus.

### Development of the Ultra-Linear Cartridge

In the last few years, ceramic cartridges have been available for use in commercial home phonographs. A ceramic of this type has sufficient output voltage to replace the majority of Rochelle Salt units. However, response has been restricted to 4000 to 5000 cps. This limitation has usually been considered desirable. In fact, some manufacturers have required a 2500-cps "roll-off" to minimize surface noise and distortion.

In contrast to this performance, basic requirements for the Ultra-Linear ce-

ramic cartridge were set up as follows:

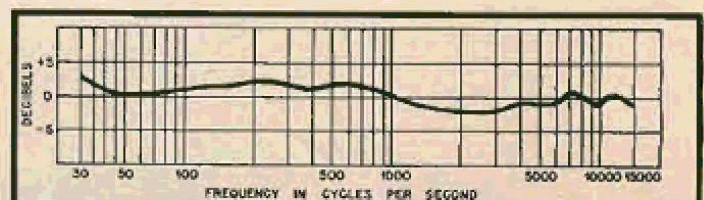
1. Frequency response was to fall within 2½ db of the New Orthophonic curve throughout the range of 30 to 15,000 cps without requiring equalization in associated equipment.
2. Output voltage was to be adequate to drive standard amplifiers without preamplification.
3. Lateral compliance should be  $3.0 \times 10^{-6}$  cm/dyne or higher, with maximum allowable damped vertical compliance consistent with mechanical stability in all arms and changers. These values are important factors in reducing record and stylus wear.
4. The stylus should be replaceable and of a standard type.

Reinforcing the high-frequency response above the constant amplitude level a required amount is one of the most important problems of adapting an amplitude device to a complex curve such as the Orthophonic characteristic. This is often accomplished by allowing the system to resonate in this range and damping to the desired level. The result is a somewhat peaked response falling off rapidly above resonance. Needle impedance can become quite high in such cases producing mis-tracking, distortion and actual damage to the record groove.

### Damping Methods

Damping is necessary in any cartridge and can be applied in a number of ways. Common practice is to rely on materials such as viscoloid, audioid, and various rubber compounds. While they are usually necessary for mounting and restraining the element, undesirable stiff-

Fig. 8. Frequency response of E-V model 84 cartridge



ness and temperature instability result if these materials are used entirely. The property of a viscous material (a true mechanical resistance) can be expressed as:

$$F = kv$$

where  $F$  = force developed upon an immersed body,

$k$  = a constant dependent upon the viscosity of the material,

$v$  = velocity of motion.

If the viscous material were utilized as a fulcrum or restraining medium on the element, the applied force or "drive" would be greater at the higher frequencies where the velocity is increasing. Thus it is possible to incorporate a resistance for damping purposes and, at the same time, to reinforce the high-frequency response. A very low "Q" can be obtained, which is essential for a smooth response.

Viscous loading of the element is used in this cartridge by surrounding the ceramic with a viscous material. Coupling to the viscous material is adjusted to the correct value by means of a small metal vane attached to the midpoint of the ceramic. The material itself is a silicone prepared for this application in which values of viscosity, plasticity, mass, and stiffness have been established for optimum results. Silicone has excellent chemical and physical stability, particularly with respect to temperature.



Fig. 7. Equivalent of pickup having a capacitive impedance working into a resistance load shunted by stray and circuit capacitance.

#### Equivalent Circuit

Equivalent circuits using electro-mechanical analogies are often useful in understanding the operation of a mechanical system. The equivalent circuit of the Ultra-Linear ceramic cartridge is shown in Fig. 6. The conversion of mechanical energy to electrical energy is represented by the transformer  $T$ .  $R_l$  is the actual load resistance on the cartridge.

#### Input Circuits

The electrical circuit of any piezoelectric device can be represented by a capacitance in series with a generator, as in Fig. 7. It should be recognized that the shunt capacitance of a lead and input circuit directly across the cartridge will not affect the frequency response to a noticeable extent. A voltage divider is set up consisting of the reactances of the ceramic capacitance ( $X_c$ ) and the shunt capacitance ( $X_{cs}$ ). The ratio of these reactances is constant at all frequencies. The net result is a given reduction in signal voltage at all frequencies.

The low-frequency response of a ceramic cartridge, however, is directly dependent upon the value of load resistance

( $R_l$ ). At low frequencies,  $X_c$  becomes appreciable and a smaller portion of the signal is available across  $R_l$ . For this reason, a minimum load resistance of 3 megs is recommended for flat bass down to the lowest frequency permitted by tone arm resonance.

Output at 1000 cps is 0.6 volt as measured on the RCA 12-5-49 V frequency test record. This record represents the normal reference level for microgroove recording. Figure 8 illustrates an actual response curve taken on the RCA record.

Distortion tests, using the Cook "N-A Beam" test record indicate inter-modulation well below 2 per cent throughout the entire recorded range. This method is specified as it is easily duplicated and evaluated by anyone without special equipment.

Extensive "A-B" listening tests have corroborated all laboratory data and demonstrated the improved performance of the Model 84 Ultra Linear ceramic cartridge.