HOW THE NEUMANN U-67 MICROPHONE SOLVES LONG STANDING PROBLEMS

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GOTHAM AUDIO CORPORATION

Even though there is a wealth of objectively measured data available from the manufacturers of high quality condenser microphones, there is no doubt that every recording engineer will testify to the fact : Microphones with identical technical specifications and measurements can display enormous individual differences. Each microphone type has something of an individual character, and every experienced recording engineer will decide on one or the other type depending on the problem at hand.

If one seeks, as an assignment, the construction of one microphone suitable not only for one particular type of recording but for a variety of recording tasks, one must first seek the physical causes which lend a microphone this individuality. Condenser microphones as a group count as one of the foremost transducer classes when examining those attributes on which the quality of reproduction directly depends. Those attributes are in the main frequency characteristic, freedom from non-linearity or distortion, lack of self-noise, as well as the directional characteristic and its non frequency dependent character.

FREQUENCY RESPONSE:

The frequency response of the field transmission factor, commonly referred to as the "frequency response", of a universal microphone as described here, should be linear within the audible range. Specification sheets generally give the response for a nearly direct incident, reflection-free sound field. This is obtained by measuring in a diffused sound field at a distance of about three feet from the sound source. It is, however, vital to note that this response only seldom agrees with the response encountered in actual practice. Corrections in both the upper as well as the lower frequencies may be necessary to "linearize" the effective frequency response.

Lower Frequencies: Velocity or pressure gradient microphones -- therefore practically all directional microphones -- display a considerable rise at low frequencies when the sound source is brought within close range of the microphone. "Close range" begins at a distance of about one wave length; i.e. for 100 cps at a distance of some 10 feet! Measured values are shown in Figure 1 below.

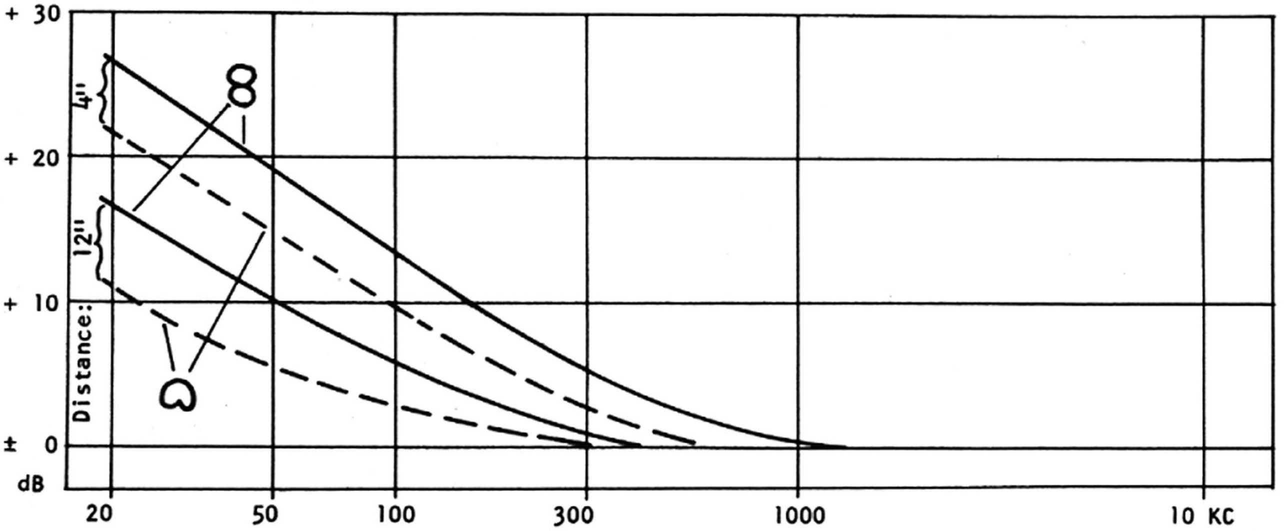

FIG. 1 Transmission factor of a **PRESSURE GRADIENT** microphone without (Figure-8) and with (Cardioid) acoustical delay, in close proximity of a sound source (non-directional).

It is not uncommon that soloists and speakers approach such a directional microphone, thereby causing pre-emphasis of up to <u>20 dB</u> at low frequencies. An electrical compensation is, of course, possible but it should take place as early in the transmission chain as possible, so that even the first amplifier stage is protected from overload caused by this ten-fold increase in low-frequency amplitudes. Close talking on mike can even produce sound pressures in excess of 100 µbar without this pre-emphasis.

Condenser microphones commonly have the first stage of amplification in the microphone itself, and a low-frequency cut-off is only possible after that. It is therefore understandable that the recording engineer chooses for such tasks either a non-directional pressure microphone (such as the KM-53a), or switches - consciously or unconsciously - to such directional microphones which avoid the low-end boost at close range. These can then, however, not be used at a distance due to insufficient low frequency response.

In an effort to satisfy both requirements, and to produce both at close range and at a distance a satisfactory sound picture, the here to be described Neumann U-67 microphone has the ability to reduce its low-frequency response starting at about 300 cps by means of a switch, so that it appears reduced at the grid of the first tube. One is then free to decide whether the microphone should produce linear response either at close range (8 - 12") or at a distance (30"+). This eliminates the necessity of carrying special microphones for both applications.

<u>High Frequencies:</u> At high frequencies as well, the distance of the sound source from the microphone determines the deviation of the obtained response from the response given by the manufacturer, especially for recording indoors. Three specific influences play a part in this:

1. The reflected sound from walls, floor, and ceiling increases with increasing distance between microphone and sound source, while the direct sound becomes weaker.
2. The microphone's directional characteristic becomes <u>more directional</u> towards higher frequencies.
3. The room's surfaces reflect sound waves unequally; higher frequencies are normally reflected to a lesser degree (in well treated rooms), and, especially in larger rooms, are further weakened by air friction.

The energy content of the reflected sound portions exceeds, even at relatively small distance from the microphone, the direct sound portions. The distance at which the energy contents will be equal can be calculated. For a room with a volume of 10,000 cu.ft. and a reverberation time of 1.7 seconds this distance is about 4 feet for both non-directional sound source and microphone. For cardioid or figure-8 characteristic microphones this has to be multiplied by a factor of 1.71.

Let us assume first that our microphone has an identical directional characteristic for all frequencies: in this case only influence 3) becomes apparent, and in a way in which it would also be true for an actual listener present, and therefore allowable. A change of distance does change the ratio between direct incident and reflected sound and with it the room impression, NOT, however, the frequency response (if we neglect influence 3).

Should the directionality of the microphone, however, increase with higher frequencies, then only part of the arriving reflected sound, which increases with ever increasing distance, will be received by the microphone; i.e. recordings in a predominantly "diffused sound field" suffer from a lack of high frequency content, UNLESS the roll-off is corrected for by a rise in the microphone's transmission factor in the same frequency range (as an example the Neumann M-50b).

Actually the latter is true for practically all of the condenser microphones built to date and for many other microphone types as well; for incident sound from the front - simultaneously with increased directionality - a rise in sensitivity by a few dB (Fig. 2A). The necessary consequence of this: these microphones give a linear response curve ONLY for one specific ratio of direct to reflected sound; i.e. in each and every room at only ONE specific distance from the sound source. For lesser distances the high frequency content becomes too strong -- for greater distances too weak.

In the main the rather "sharp" sound impression which such microphones give at close range has led to the expressed wish for a microphone, which, even for close miking. gives a linear response to the highest audible frequencies without the usual "peak", while at the same time, by virtue of its non frequency-dependent characteristic (pattern), becoming only slightly less sensitive (Fig. 2B).

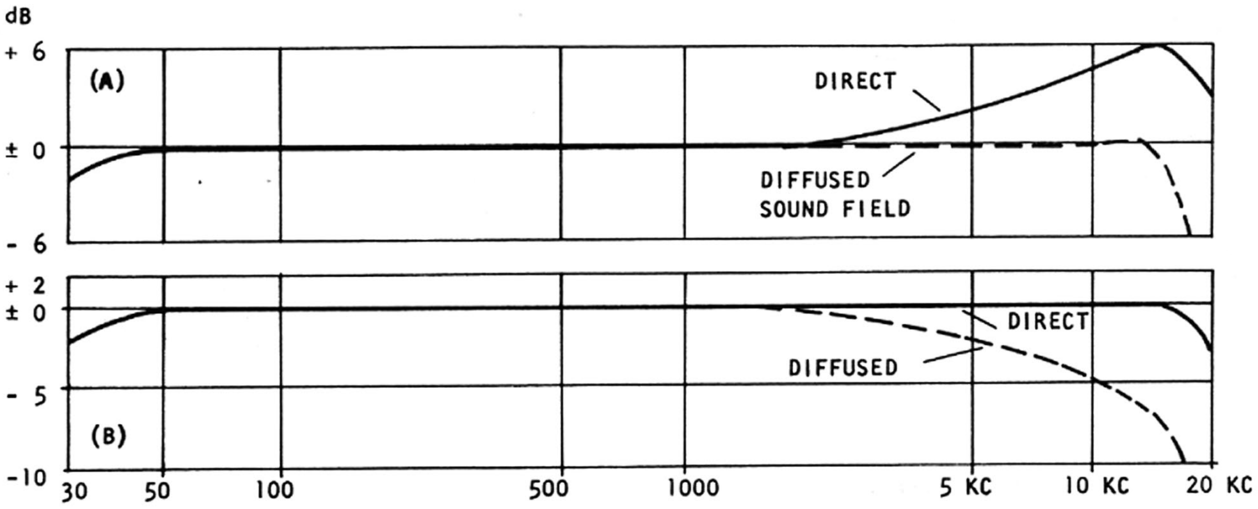

FIG.2- DESIRED FREQUENCY RESPONSE IN TWO MICROPHONES OF DIFFERENT APPLICATION

(A) Microphone for distant pickup -- flat in diffused sound field.
(B) Microphone for close pickup ---- flat in direct sound field.

NON FREQUENCY-DEPENDENT DIRECTIONAL CHARACTERISTIC:

This wish is rather difficult to fulfill. Pressure microphones which remain non-directional at 15 KC, and directional microphones which are to operate according to the pressure gradient principle up to 15 KC must of necessity be no more than a few milimeters in diameter. All of the hitherto available microphones are considerably larger than that in size, since demands for a satisfactory signal-to-noise ratio and operational ruggedness could otherwise not be satisfied.

This results in the first mentioned properties: increasing directionality because of interference and shading effects, with simultaneous increase in transmission factor for front incident sound due to pressure "build-up". Pressure gradient microphones only remain linear in their output voltage as long as the time delay with which the sound reaches the rear membrane, remains smaller than one half the length of one sound wave. For the customary dimensions of such a microphone this is possible only up to a discrete frequency which still lies in the middle of the range of audibility.

One comes closest to the desired solution if one builds up the unit to operate as a non frequency-dependent figure-8 or cardioid up to a specific frequency. Above this frequency one lets it transform rapidly into a pressure receiver. Since it only acts as a pressure receiver for less than two octaves, the unavoidable increase in directionality in this frequency range, can be held to tolerable limits.

CAPSULE CONSTRUCTION:

The U-67 capsule is, like many of its predecessors, equipped with two membranes, which according to a suggestion by Braunmühl and Weber (1935) are arranged on either side of a common electrode. Each system alone has a cardioid characteristic.

An in-phase electrical combination of the two membranes results, as a superimposition of two cardioids, in a non or omni-directional characteristic. Out-of-phase combination (achieved by reversing polarity of one of the bias voltages) results in a Figure-8 characteristic (Fig. 3). Cardioid characteristic results when only one membrane is connected. The switch for selecting the three characteristics is located at the base of the capsule mount.

Both membranes operate, in connection with the symmetrically arranged common electrode, as pressure gradient units to a frequency of 4-5 KC (cardioid characteristic), and above that frequency as high resonant pressure receivers. With its diameter of 32 mm (1 3/16") each capsule half already behaves nearly like a one-sided cerdioid above the transition frequency, due to shading and interference effects. It further becomes nearly circular (uni-directional) at 12.5 KC therefore still allowing an included sensitivity angle of nearly 90° (Fig. 4 - cardioid of U-67 at 1, 4, 12.5 KC).

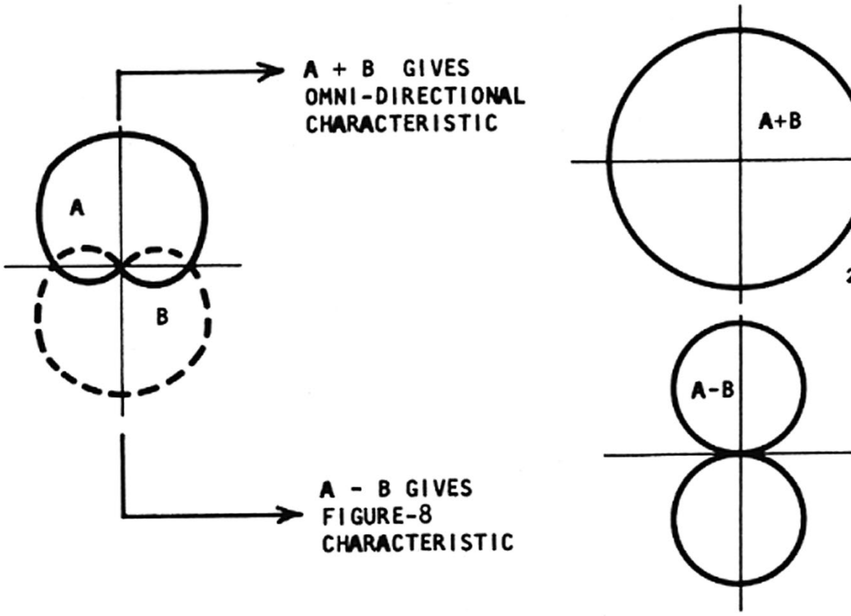

FIG. 3 - DERIVATION OF OMNI-DIRECTIONAL AND FIGURE-8 PATTERNS FROM SUPERIMPOSITION OF TWO CARDIOIDS.

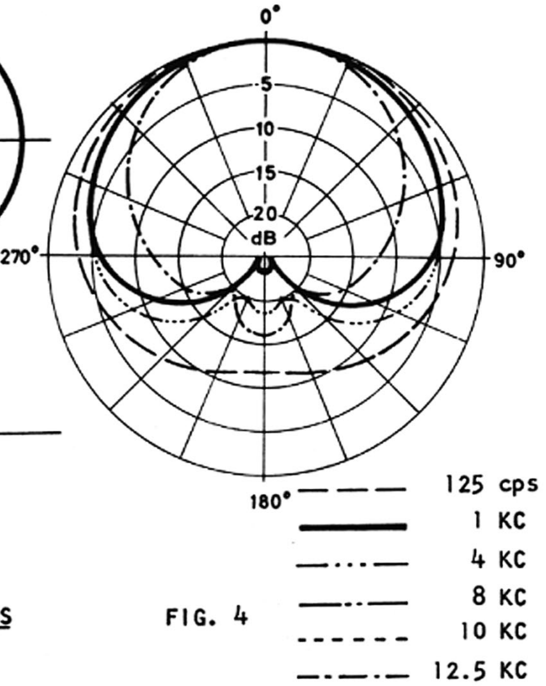

FIG. 4

Special care was used in the dimensioning of the acoustical time delay element in the common electrode. It is in the main the determining factor of the cardioid characteristic below 4 KC., and must present below this frequency a reasonably constant delay to the sound wave. To make the capsule into a high-resonant pressure receiver above 4 KC, it is necessary for the common electrode not only to be "sound tight", but it must display elastic properties which, together with the membrane, make for a high-resonant system. To accomplish this the common electrode was constructed as an acoustical low-pass element by properly dimensioned holes and slots. The analogous circuit is shown in Fig. 5, while Fig. 6 shows the response curve of the sound pressure passed through the acoustical filter.

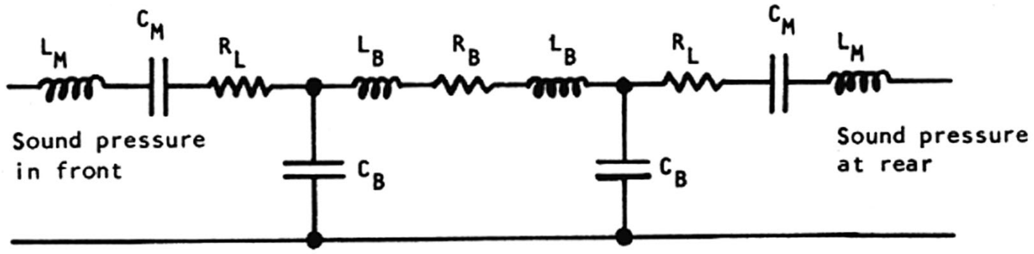

Fig. 5 - Equivalent Circuit of a Double-Membrane Condenser Capsule as found in the **NEUMANN U-67** Microphone.

L_B = Membrane mass
C_M = Elasticity of the stretched membrane
R_L = Air friction in space between membrane and fixed electrode.
C_B = Elasticity of air in air cushion behind membrane including outside drilled holes and dead end holes in fixed electrode.
L_B,R_B = Mass and friction of air (resistance) in the narrow drillings and the slot in the fixed electrode.

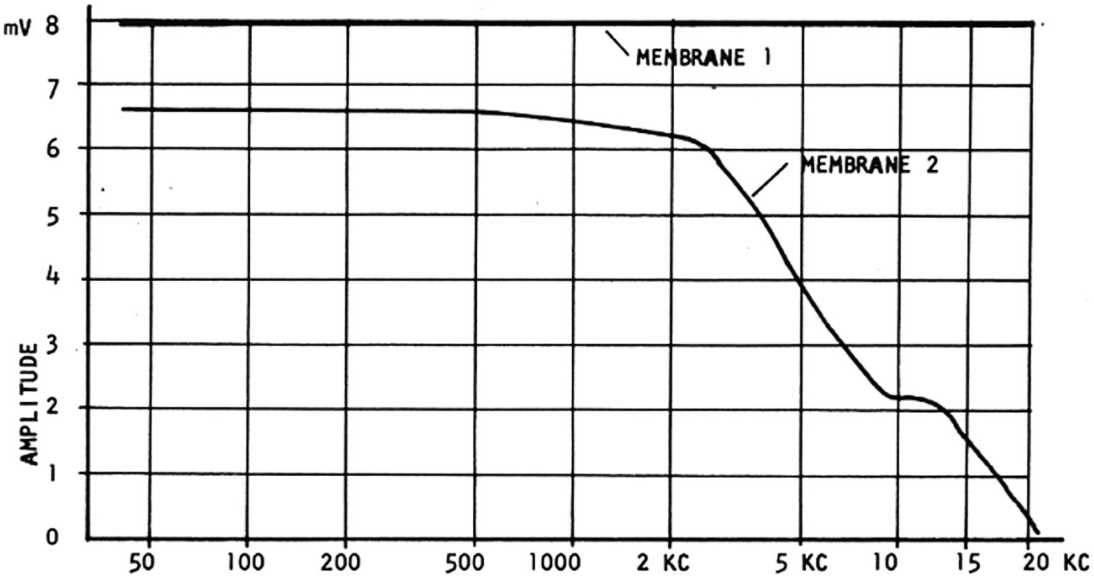

FIG. 6 - MEASURED SOUND PRESSURE IN FRONT AND BACK OF FIXED ELECTRODE OF U-67 MICROPHONE
Membrane 1 is brought to vibration electrically, while membrane 2 is connected as a sound receiver. The fixed electrode acts as a low-pass filter by virtue of its special construction.

As with all low-pass filters, this one has in its pass-band (in a certain range below 4 KC), a relatively constant time delay. This time delay in combination with a small, artificially produced labyrinth, results in a simultaneous arrival of sound waves from the rear at the rear membrane, with those arriving by going around the capsule to the front membrane. This phase relationship constitutes one of the two requirements for a good front-to-back rejection of the capsule in cardioid operation. To satisfy the amplitude requirement, both the sound waves arriving at the rear as well as the front membranes must exert equal forces. The damping of the acoustical filter through R_B may only be small at low frequencies, since these are led nearly undamped around the capsule to the front membrane. However, as soon as the rear incident sound pressure becomes weaker at the front membrane through shading effects, and stronger at the rear through "build-up", then the low-pass damping must increase relatively quickly.

Above 4 KC the acoustical inductance, L_B, represented by the air mass of two neighboring holes and a slot, becomes practically impervious to sound. L_M, up to now negligible compared to R_L, forms, together with the elasticity C_B, caused by air which is in the larger holes and dead-end holes in back of the membrane, a 15 KC series resonant circuit, highly damped by R_L. This assures that the membrane, now operating as a pressure receiver, still performs non frequency-dependent excursions with constant sound pressure.

R_L was adjusted by proper choice of hole and membrane spacing to insure that there would be virtually no response increase towards the higher frequencies for front incident sound. The proper choice of R_L is particularly critical, since R_L represents a part of the friction damping which the membranes require in the lower frequency range in order to insure constant excursion even when operating as pressure gradient units.

NON-LINEAR DISTORTION:

One might be of the opinion that the subject of non-linear distortion need not be mentioned in a discussion of condenser microphones for studio use. The capsules in common use produce noticeable distortion only beyond the threashold of pain. On the other hand some of the older microphone amplifiers are already easily overloaded by the sound pressures commonly delivered by the capsule in close range miking techniques. One must nevertheless observe that such microphones find general acceptance even when recording loud instruments at close range. This leads one to the conclusion that in special cases the production of harmonics may be desirable for lending "brilliance" to single instruments by virtue of the addition of such harmonics. This, of course, concerns only monotonic instruments, since combination products from overtones surely must be undesirable in all cases.

The U-67 microphone contains a voltage amplifier with a "normal" overload boundary. Sound pressures beyond 125 µbar, as may be found in the aforementioned special cases, could therefore produce unwanted harmonics. In keeping with its "universal" character, this microphone is additionally equipped with a switch which inserts an electrical "pad" between capsule and amplifier grid, making possible the recording of the highest imaginable sound pressure levels without distortion. This switch also gives operational advantages: without this insertable pad excessively loud instruments could not be gain controlled properly on the console, since the fader position would be too low, and the input stages of the preamplifier in the console would be subjected to overload as well.

PSYCHOACOUSTIC CONSIDERATIONS IN CONDENSER MICROPHONES:

Human hearing is relatively insensitive to low frequency alternating sound pressures as well as to direct pressures as are found in wind. It is interesting that such lowest frequency sound pressures which are oftimes found in nature, can surpass by many times the normally heard sounds which reach the ear. If the ear were equally sensitive to these components as it is to midrange sound pressures, it would lead to serious impairment of hearing.

In sharp contrast to hearing, the best microphones may not, unfortunately, display within the transmission range a similar low end roll-off, and therefore do not enjoy the same natural protection against high pre-emphasised lowest frequency sound pressure components. High quality music reproduction generally demands a lower frequency limit of 30 - 40 cps for the transmission channels and therefore also for the microphone.

Experience has shown that a frequency range exyending to the lowest frequencies must be won at the expense of great wind and mechanical shock sensitivity, especially with gradient microphones. To correct this situation, the following are some of the well known countermeasures which have been used: A high-pass filter in the subsequent transmission chain to block the pre-emphasised low frequencies. This solution has the serious disadvantage that possible overload either of the microphone system itself or of the preamplifier tube (in condenser microphones) can not be avoided Another solution is the use of a wind screen consisting of either a wire or cloth mesh around the unit itself, whose function it is to keep from the microphone air currents or lowest frequency sound pressures. Low frequency mechanical shock transmission to the microphone is prevented by the use of an elastic suspension. Both of these measures, however, have the distinct disadvantage of increasing the physical dimensions greatly, and it is furthermore often impossible, for operational reasons, to make the elastic suspension sufficiently soft. A further known solution in condenser microphones is to make the input resistance of the microphone's amplifier tube -- usually at the same time the grid return -- so small, that the low frequency components of the signal are reduced through the internal drop of the capsule. Unfortunately this solution brings with it a considerable rise in self-noise level of the condenser microphone. This is so because the greater the input resistance of the microphone amplifier for a given capsule capacity, the lower the frequency down to which the resistor and grid current noise are electrically shorted by the capsule capacitance. Also among the remedies implemented by some manufacturers has been a microphone system with a higher resonance point. By creating an acoustical labyrinth for low frequencies only a situation manifests itself in which, for low frequencies, the driving pressure gradient increases simultaneously with the mechanical resistance of the moving system. This sort of solution cannot, however, be carried too far if the normal dimensions for microphones are not to be exceeded.

A NEW AMPLIFIER CIRCUIT DESIGN FOR THE U-67 MICROPHONE:

In an effort to avoid all of these disadvantages, a new amplifier circuit has been invented (Pat.Pend.) for condenser microphones. A part of the signal at the plate of the microphone amplifier tube is connected through a three or more part chain consisting of series resistors R_1 to R_3, and parallel condensers C_1 to C_3, back to that terminal of the capsule which is not connected to the grid of the tube. This terminal then is connected to ground through the last parallel condenser of the chain, C_3, while C_3 and R_4 for a further feedback loop.

This amplifier circuit has the advantage that low frequency components below a defined boundary frequency are highly attenuated at the amplifier itself through use of small and space saving components without the use of inductances. At the same time there is not attenuation in the neighboring frequency range directly above the boundary frequency. As a result overloads and the well-known "blocking" effects caused by exaggerated excursions of the capsule's diaphragm due to wind or mechanical shock intereference can be practically eliminated. This has not been possible with the band-pass devices used heretofore.

Since the feedback voltage enters the capsule at its low side, there is no change in the grid input resistance and therefore this method has no effect whatever on the self-noise level of the microphone.

Another noteworthy advantage of this circuit is the fact that the source impedance of the microphone system output remains constant down to the boundary frequency, and only becomes smaller below that point. The frequency response is therefore not a function of the load impedance which follows, as is the case with almost all other circuits for low frequency cutoff.

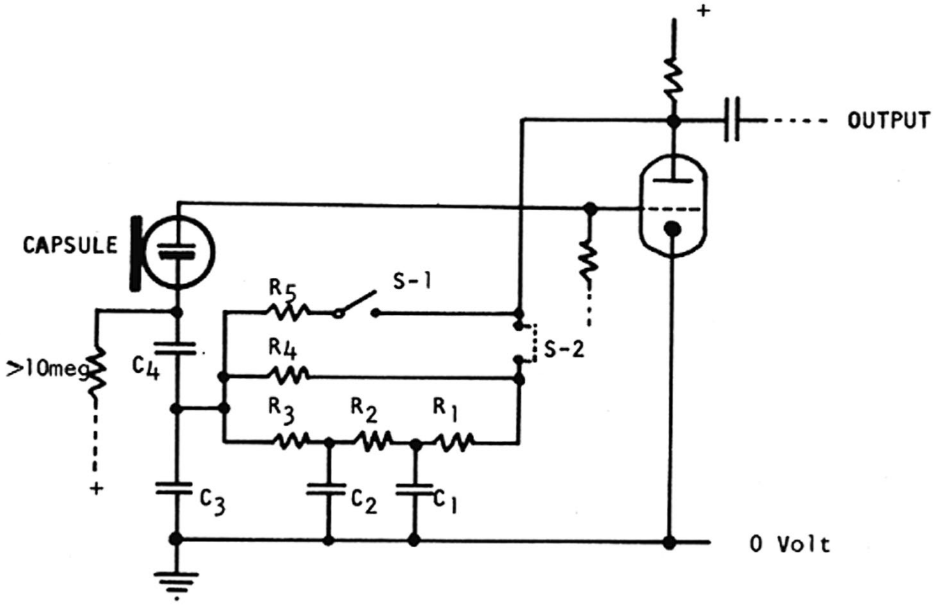

FIG. 7 -- BASIC SCHEMATIC OF CONDENSER MICROPHONE PREAMPLIFIER

The functions of the new amplifier circuit can best be described using the following illustrations:

Figure 7 shows an example of a one tube amplifier for a condenser microphone, as it is found in the U-67.

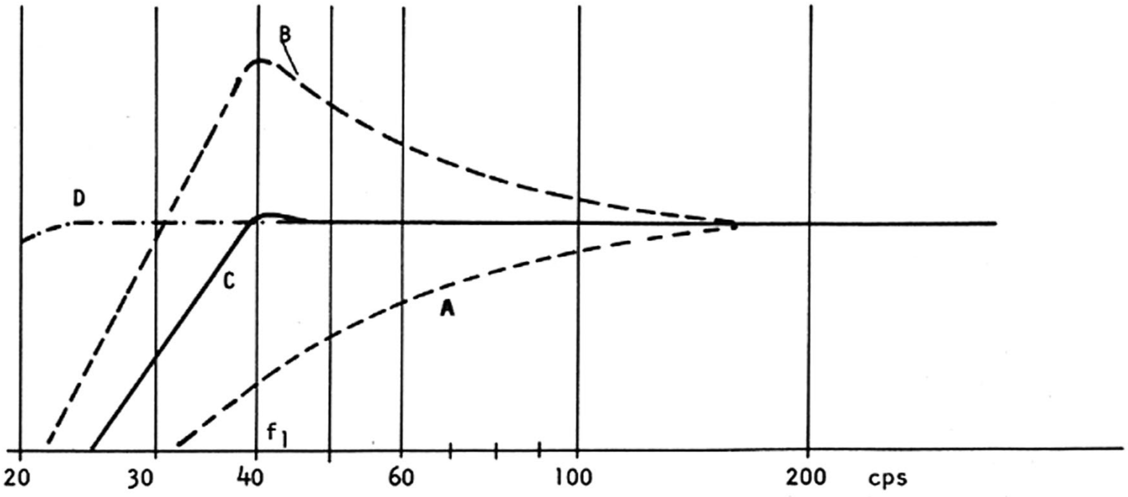

FIG.8 -Curve A -- Response resulting from combination of R_4 and C_3.
Curve B -- Response resulting from combined network R_{1-3} and C_{1-3}.
Curve C -- Combination of curves "A" and "B".
Curve D -- Resultant response with S-2 opened.

Figure 8 shows the curves of the transmission factor of the amplifier as a function of frequency. While these are theoretical values, performance is almost identical.

In the amplifier shown in Fig. 7 the microphone capsule is connected as a generator to the grid of the tube, whose grid bias comes from the grid resistor shown. The polarizing voltage necessary for the operation of a condenser microphone is generated across the resistor leading to the capsule.

The mixture of positive and negative feedback from the plate of the tube to the low side of the microphone capsule goes through the three-part RC chain with series resistors R_{1-3} and parallel capacitors C_{1-3}. The low side of the microphone capsule is not at ground potential directly but rather through the last parallel capacitor C_3 of the chain. The capacitor C_4 is strictly a DC blocking capacitor. The AC voltage at the plate is 180 degrees out of phase with that at the grid. The above mentioned three-part RC chain is so chosen that it produces at a given critical frequency - preferably at 40 cps - another 180 degrees of phase shift. In the case of this three-part chain each part was dimensioned to give a 60 degree phase shift. Calculation is similar to that for a phase shift generator. In order for it to oscillate such a generator requires, however, an amplification of 29 for a three-part chain and 18.4 for a four part chain, as long as these are composed of equal "links". In the case of the microphone amplifier, this amplification factor is purposely held below that value and is furthermore reduced towards the low frequencies through use of a frequency selective feedback loop to prevent any self-excitation.

The second feedback path which is superimposed on the first is through R_4 and C_3 and has, by itself, a response which drops off towards the low end corresponding to curve "A" in Fig. 8. If only the feedback path through the RC chain is used, it results in a response according to curve "B". This means that for higher frequencies the chain becomes increasingly less conductive and therefore less effective. On both sides of the 40 cps point we get positive feedback whose magnitude, in the main, depends on the amplification factor of the tube (= 360° at 40 cps), which changes at = 450° (towards lower frequencies) back into negative feedback. A superimposition of both positive and negative feedback loops produces a response curve as shown in Fig. 8 as "C", when proper components are selected.

The response slope of a circuit as in Fig. 7 can be made extremely steep; or it can be reduced as needed by simple addition of a non frequency-dependent feedback loop. Both the critical frequency of the entire circuit as well as the critical frequency of R_4C_3 can very simply be made switchable. For the first case the value of C_3 and perhaps one of the resistors R_{1-3}, and for the second case the value of R_4 can be made variable either continuously or in steps.

For transmission of music and speech the second possibility assumes tremendous importance especially for directional microphones which operate according to the pressure gradient principle; i.e. entirely or partially as a velocity receiver. As mentioned earlier in this article the sensitivity of a pressure gradient microphone at 40 cps at a distance of 4" is ten times that at 1000 cps for the same sound pressure. The microphone already operates with sound pressures on the order of 100 microbar at such close range. The capsule can handle this without distortion, but the amplifier cannot. It is therefore of advantage if the aforementioned low frequency rise is compensated through use of this circuitry at the grid of the tube to prevent tube overloading.

In the circuit in Fig. 7 the switch S-1 would be closed for sound sources in close proximity of the condenser capsule, which would then result in a <u>restoration</u> of linear response of the transmission factor (NOT a cutoff at the low end).

Switch S-2 can be used when the low-frequency cutoff is not desired, for instance when organ recordings flat to the lowest frequencies are to be made in an environment free from low frequency disturbances. Curve "D" in Fig. 8 can then be obtained and the microphone amplifier's response made linear to below 20 cps. Choice of a greater value for R_4 can also produce a rising response to the border frequency, should that be desired.

If the value of R_5 is so chosen as to reduce the value of R_4 to about 1/3 its original value when S-1 is closed, then proper compensation for this pressure gradient microphone would be obtained to produce linear response for a sound source approximately 8" away from the microphone capsule.