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Contents

Prepolarized Condenser Microphones for Measurement Purposes

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ABSTRACT

Two prepolarized condenser microphones have been developed. For stability reasons they have metal diaphragms like other B & K measuring microphones. Their prepolarized elements (electrets), which have high humidity and temperature stability, are placed on the backplates. As the mechanical design is identical to B & K microphones with external polarization, and as the electrets imply extra costs, the prepolarized cartridges are relatively more expensive to produce.
The prepolarized cartridges do not offer any additional acoustical advantages, but in the design of sound measuring instruments the extra costs may be repaid by simplification of preamplifiers and power supplies, or by space or power saving in small, especially pocket sized, battery operated instruments.

SOMMAIRE

Deux microphones à condensateur prépolarisés ont été développé dernièrement. Pour des raisons de stabilité, ils sont, comme tous les autres microphones de mesure B & K, dotés d'une membrane métallique. Leurs éléments prépolarisés (électrets), qui ont une haute stabilité à l'humidité et à la température, sont placés sur leur plaque arrière. Dans la mesure où la conception mécanique est identique à celle des microphones B & K avec polarisation externe et que l'emploi d'électrets implique une dépense supplémentaire, les cartouches prépolarisées sont relativement plus coûteuses à produire.
Les cartouches prépolarisées ne présentent pas d'avantages acoustiques supplémentaires, cependant leur coût plus élévé pourra être contrebalancé dans la conception des appareils de mesure par une simplification des préamplificateurs et des alimentations ou par une économie de place ou de consommation, particulièrement pour les instruments, format de poche, alimentés sur piles.

ZUSAMMENFASSUNG

Es wurden zwei Kondensator-Mikrofone mit interner Polarisation entwickelt. Aus Stabilitatsgründen wurden diese, wie andere B & K-Meßmikrofone, mit einer Metallmembran ausgestattet. Das polarisierende Element (Elektret) ist bezüglich Feuchte und Temperatur äußerst stabil und auf der Gegenelektrode montiert. Die mechanische Konstruktion ist mit der von B & K-Meßmikrofonen mit externer Polarisation identisch und da durch das Elektret zusätzliche Kosten entstehen, sind die Mikrofonkapseln mit interner Polarisation verhältnismässig teurer in der Herstellung.

Die Mikrofone mit interner Polarisation bieten keine weiteren akustischen Vorteile, jedoch machen sich bei der Konstruktion von Schallmeßgeräten die aufgewendeten Extrakosten bezahlt, indem Vorverstärker- und Versorgungseinheiten vereinfacht und die Konstruktion von energiesparenden, kleinen (Taschen-) Geräten mit Batterieversorgung möglich ist.

Introduction

An electrical charge must be applied to a condenser microphone if its operation is based on the usual principles. This charge may be supplied from an external source or, using a newer technique, it may be permanently stored in a charge-carrying element which is built into the microphone cartridge itself by the manufacturer. The polarized element is called an electret.

As relatively few people are acquainted with the behaviour of electrostatic charges or the special branch of that field dealing with electrets, the majority are surprised to learn that some materials can maintain an electrical charge for thousands of years. It is interesting that so little is known about it, even though man's first direct acquaintance with electricity must have been with an electret. It is known that the Greeks knew about amber, and its strange behaviour when rubbed, as early as 600 B.C. Compared with electrets being produced today, amber loses its charge very quickly. The reason so little is generally known about electrets is that they have been used for very few applications from the time they were discovered until today. Among a few other applications, they are now being widely used for prepolarizing condenser microphones.

During the last ten years these new prepolarized condenser microphones have dominated the consumer market, i.e. for applications in cassette recorders, radio sets, hearing aids, public address systems, etc., and they are gaining part of the telephone market. Dynamic microphones and piezoelectric microphones, which earlier covered many of these less critical applications, are being superseded. The change occurred because cheap semiconductors became available for matching the very high electrical impedance of the condenser microphone to the lower one of the associated equipment, and additionally because electrets of reasonable stability were developed in the late sixties and early seventies. This was a step in the direction of improved acoustical performance as the door opened to condenser microphones in applications where other types were dominant in the past.

Even though more than 100 million electret microphones are being produced yearly for non-professional purposes, the prepolarized condenser microphone has not yet noticeably influenced the field of measuring microphones. However, a few years ago a development project was started at Brüel & Kjær with the aim of producing electrets of a quality level similar to the other important elements which determine the properties of a measuring microphone. The practical results of this work are two new prepolarized condenser microphones primarily intended for sound level meters standardised as Type 1 and Type 2 respectively.

This paper discusses design considerations, gives measurement results for the type of prepolarized element which has been used, describes the new microphones, and mentions applications where they could be used to advantage.

Design Considerations

With very few exceptions, all measuring microphones are condenser microphones. This microphone principle has been chosen because it complies with the general requirements of a measurement quality microphone better than other principles.

It is a basic requirement that the acoustical performance must be good in order to obtain high accuracy of measurement results.

Secondly, its sensitivity to varying environmental conditions must be low.

To obtain repeatable results, and to extend time intervals between calibrations, good short term- and long term stability is necessary.

Also, calibration ability should be good. Sensitivity and frequency response should be easy to verify; the performance should be predictable not only via direct measurements but also via calculations based on theoretical considerations, allowing independent confirmation of performance data. Therefore a simple cylindrical shape without any cavity at the diaphragm and a simple mechanical design of the diaphragm system are important design goals.

The above requirements were the design goals for the cartridges forming the B & K microphone program, and also for the development of the

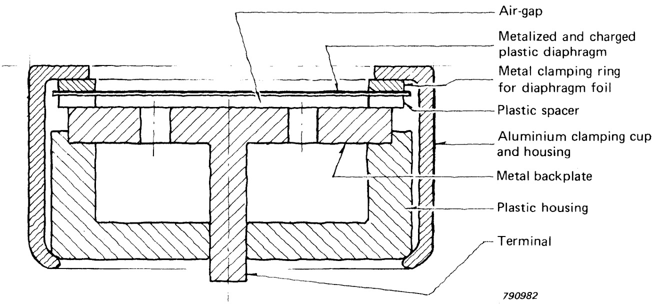

Fig.1. Typical design of mass-produced electret microphone

new prepolarized microphones. The extra complication of incorporating a charge-carrying element in the cartridge was to have minimum influence on the general performance of the measuring microphone.

In virtually all currently produced electret microphones, the electret is an integral part of the diaphragm (Fig.1). The diaphragm consists of a plastic foil which is charged in such a way that there is a difference in the electrical potential between the inside surface and the metalized outside surface which is connected to the housing. The inside surface faces the air gap and the backplate, which is kept at the same electrical potential as the microphone housing by the associated electronics. Therefore an electrostatic field is set up in the gap (Fig.2). This field corresponds to the field produced by the polarization voltage supplied to a conventional condenser microphone.

However, a plastic diaphragm is unacceptable in a quality microphone for measurement purposes. From plastic materials available today, it is not possible to make foils which can withstand the tension necessary to obtain the high resonant frequencies required for commonly used sizes of diaphragms. If this is attempted the foil will break, or sagging will lead to a decreasing diaphragm tension causing a corresponding change in frequency response, i.e. an increase in the sensitivity at lower frequencies.

One method of overcoming this problem is to reduce the tension and to support the diaphragm not only along the edge but also at one or more points over its surface (Fig.3); however, this may lead to clamping problems at the supported points and thus to short term instability. One could also choose to increase that portion of the stiffness which is due to the airfilled cavity inside the cartridge, simply by reducing cavity di-

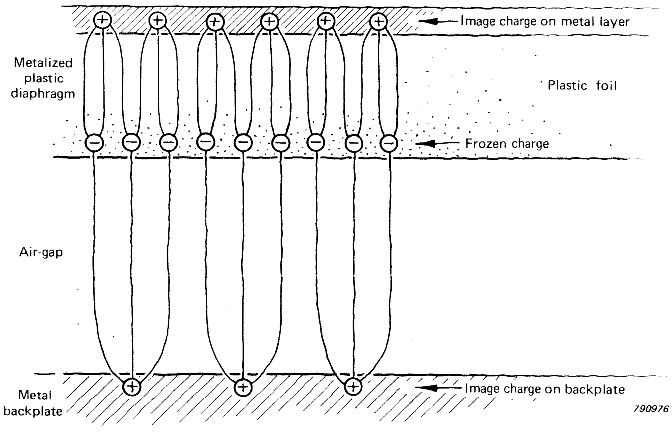

Fig.2. Sketch showing positions of charges for space charge electret in the case of the electret being an integral part of the diaphragm. The frozen charge and the charge on the backplate produce the field in the air gap which is necessary for the operation of the microphone

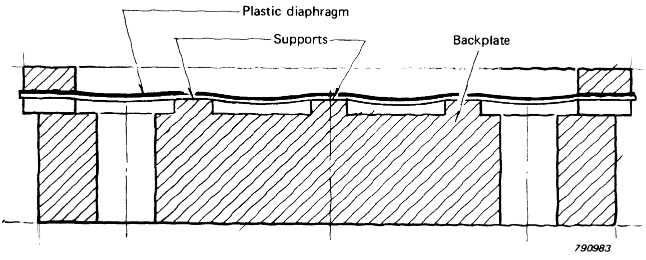

Fig.3. Sketch showing a principle used by some manufacturers to obtain sufficiently high resonance frequency of plastic diaphragms having low creep stability

mensions, a solution which, however, causes increased sensitivity to variations in ambient pressure. Nevertheless this has been done on many cheaper microphones, for some of which more than 70% of the total stiffness is air stiffness, while it is only 5 - 20% for most measuring microphones.

Additionally, plastic diaphragm microphones are more temperature sensitive than metal diaphragm microphones. The reason is the higher

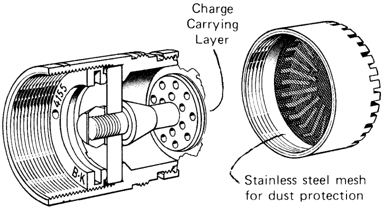

Fig.4. Prepolarized Condenser Microphone (Type 4155) of same mechanical design as other B & K measuring microphones. The electret is placed on the backplate surface to obtain the best possible mechanical stability

thermal expansion of plastics and a modulus of elasticity which varies more with temperature than it does for metals.

Considering these and other problems related to plastic diaphragms, it was decided that the new prepolarized B & K microphones should be based on the same mechanical construction as the other B & K microphones and that the electret should therefore be placed on the surface of the backplate.

Thus, direct influence of the varying and unstable mechanical properties of the charge-carrying element upon the critical moving system was avoided. Furthermore, the new microphones could profit from experience gained from the other microphones of the B & K program.

The mechanical design and the position of the electret are shown in Fig.4. Detailed information about the general mechanical construction principle and the choice of materials has earlier been given in papers and literature from B & K.

After that decision the main problem was to develop an electrically stable charge-carrying element.

Charge-carrying Element

A large number of materials have been examined for their ability to maintain electrical polarization or charge. The results have been reported in many papers by scientists from all over the world. A comprehensive description is given by S. van Turnhout in his book "Thermally Stimulated Discharge of Polymer Electrets". In addition, the book contains many references.

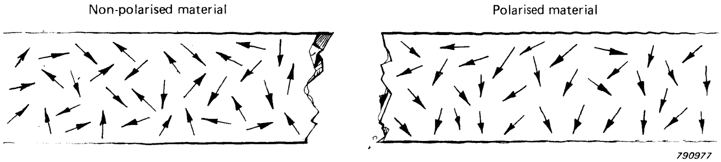

Fig.5. Sketch showing principle of dipole polarization. Note the randomness of the dipole orientation in the non-polarized material

Generally, materials may be polarized for two reasons.

In some materials, the molecules form electrical dipoles; this is the case even if the material does not cause any external electrical field, as the orientations of the dipoles are normally randomly distributed. However, if the material is softened by heat, the dipoles may be lined up by an external electrical field, and they may be "frozen" in their new orientations if the external field is maintained while the material is cooled down. After the dipoles are lined up, the material forms an external field and becomes an electret (see Fig.5).

Electrets may also be formed by inserting electrical space charges in materials having low conductivity. These charges may be positive or negative, or both types may be present. The external field strength and its polarity depends on the number of the single charges, their polarity, and their spatial distribution, as well as on the material in which they are contained. See sketch showing space charge polarization in Fig.2.

In some materials, dipole polarization and space charges may be present at the same time. The stability of the charge or polarization depends on many parameters: however, dipoles generally return to random orientation faster than space charge polarization decreases. Therefore, some of the best electret materials are materials with no or small dipole effect, and materials with a very low conductivity such as polytetrafluorethylene (PTFE-TEFLON) and its copolymerizates. Brüel & Kjær has been working with this group of materials to select the most suitable one and to find optimal ways for preparation, charging, and artificial ageing with the aim of developing a stable electret — an electret which maintains its charge under severe conditions of humidity and which can withstand high temperatures.

A high stability may be obtained because inserted space charges are present not only in the conduction band, but are also trapped in positions from which they are not able to move unless they are activated by

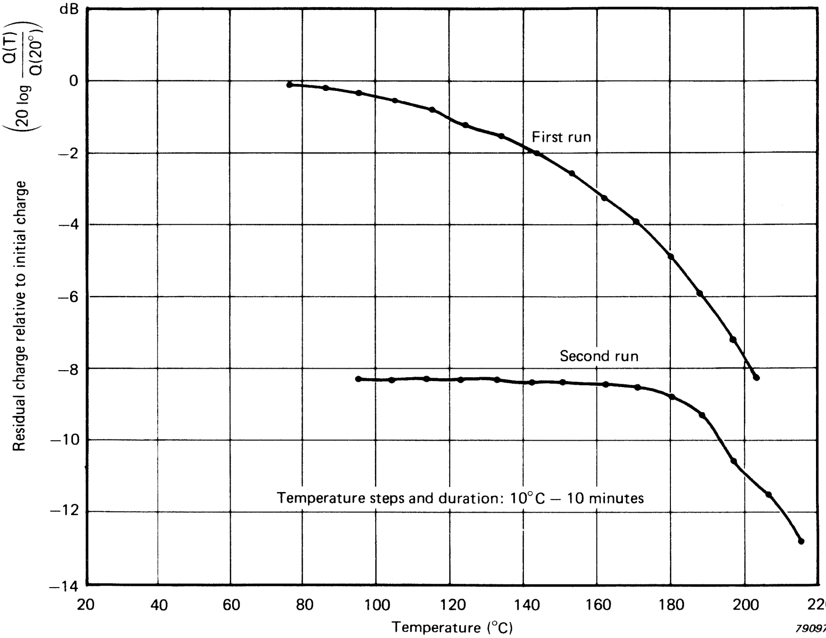

Fig. 6. Typical result of a material test. Charge decay as a function of temperature which is increased in steps. As can be seen the charges requiring only low activation energy were released on the first run

an external source of energy, for example, they may receive the energy if the material is heated. The traps in which the charges are kept are different, therefore they are also released at different temperatures. The trapping of the charges depends on the material, its preparation, and the charging process which is used.

To examine electrets, it is usual to increase their ambient temperature continuously or stepwise while the residual charge is measured. Fig. 6 shows results obtained on a sample which had been exposed to such treatment twice in succession. The temperature was increased in steps of 10°C, while the duration of exposure was 10 minutes at each step. It can be seen that in the first run some charge was released at relatively low temperatures and that the loss of charge was significant. Notice on the second run curve that no charge was released at low temperatures. The charges which required only low activation energy were

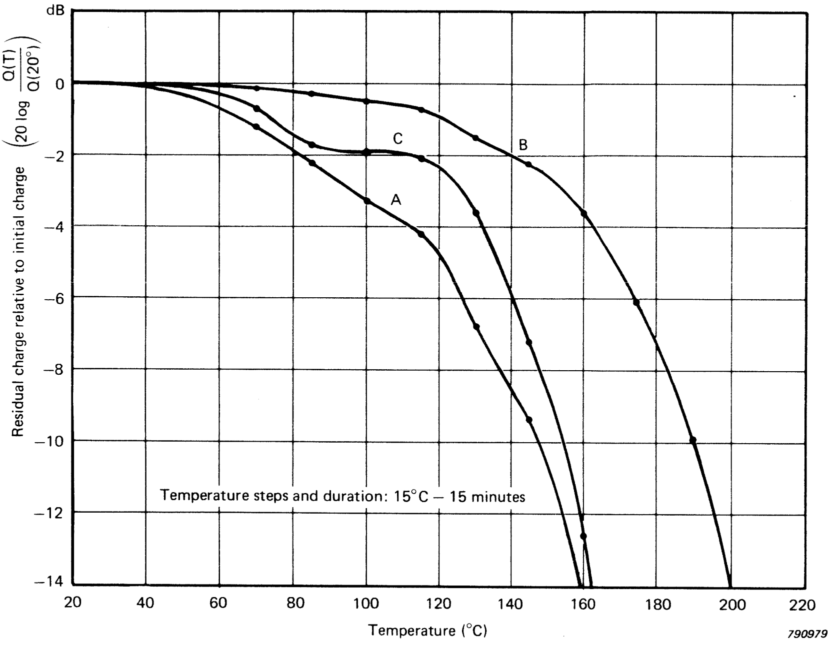

Fig. 7. Charge decay as a function of temperature. Even if the basic material is the same for the samples (A, B, C) their stability depends significantly on sample preparation and treatment

released during the first run and the remaining charge was stable until the temperature reached the range where the first run was stopped. The electret had become more stable after the first run.

An example of how much the treatment and preparation of the polymer sample influences the temperature stability is given in Fig.7; even though the basic material is the same, the resulting stability is very different for the three samples.

Within the same group of materials, differences may also be found with respect to loss of charge in humid environments. Sample A in Fig.8 shows practically no loss of charge in the initial phase, while in the long run its charge is continuously decreasing. Sample B shows an initial loss of a little less than 0,1 dB, while later on the charge remains extremely stable.

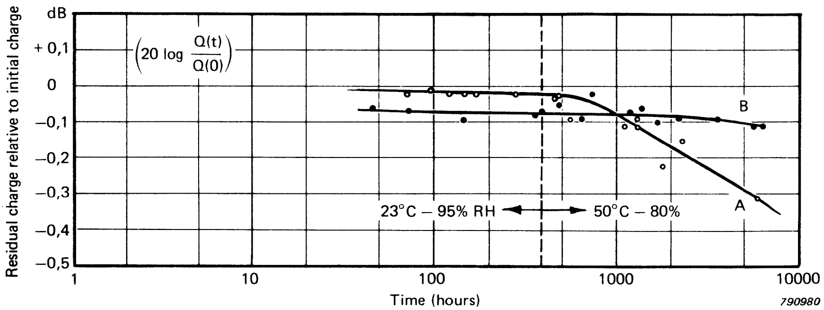

Fig. 8. Charge decay as a function of time for two different versions of PTFE material in the humid environments indicated

Stability of Electrets in Microphones Types 4155/75

After a great number of experiments in the laboratory, the final choice of material and production procedure was made. As with any other product, production of prepolarized microphones must be rational, therefore from a scientific point of view it is interesting to note that the results given here are not the extremes of what may be achieved but rather a compromise between quality and the costs of obtaining it. Single units made in the laboratory and production have shown results which are more than 10 times better than shown in the following.

The charge decay of the electret, which is almost equal to the sensitiv-

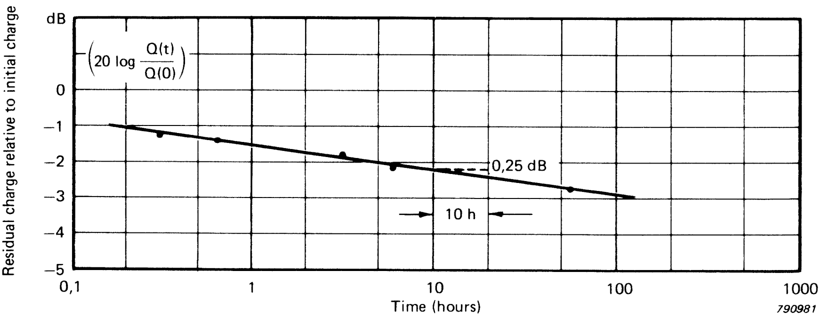

Fig. 9. Charge or sensitivity decay as a function of time at 150°C. The production procedure used for stablization corresponds to 10 — 20 hours at 150°C. Typical charge decay at the time of delivery is 0,025 dB/hour at 150°C

ity decay, is shown as a function of time in Fig.9; the curve is valid at 150°C for a typical unit. Even if the production procedure used for obtaining long-term stability differs from a continuous treatment at 150°C, the average stability of finished microphones corresponds to that gained after 10-20 hours of exposure to this temperature, approx. 40 hours/dB. The loss of charge and thus of microphone sensitivity, as well as the improvement of stability which may be expected after long-term exposure to 150°C, can be seen in the figure. The stability of the electret at 150°C is made significantly higher than the stability of the

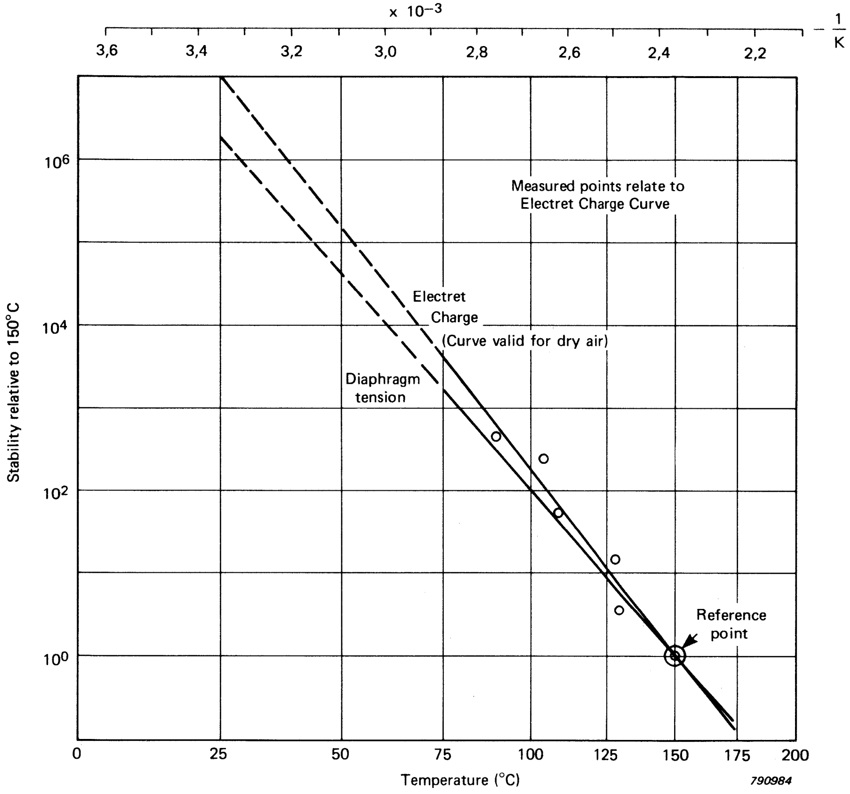

Fig.10. Stability as a function of temperature indicated for the two significant parameters; diaphragm tension and electret charge

tension of the microphone diaphragm*) for production reasons, even though it is not necessary with respect to the specifications of the microphone.

Furthermore, it has been found by experiment that the rate of increase in the stability of the electret is higher than it is for the diaphragm tension when the temperature is lowered (see Fig.10). Evaluation of room temperature stability based on extrapolation in Fig.10, combined with the stability determined at 150°C, leads to a room temperature stability of thousands of years per dB. (For practical reasons, this has not been possible to prove by direct measurements.) Thus it may be expected that the long-term temperature stability of the microphone is not limited by the charge-carrying element when a dry-air environment is considered. This means that the dry air long term stability specifications for the prepolarized microphones can be made equal to the other B & K microphones for which the diaphragm tension is the limiting parameter.

The rate of the discharging process of the electret is influenced not only by temperature but also by humidity. Fig.11 shows the remaining charge as a function of time when the microphone is exposed to 50°C and 90% RH. The loss of charge is shown as a function of the square root of the time, as in practice it gives a good fit to a linear function for smaller changes (< 1 dB). Therefore, the stability can be expected to in-

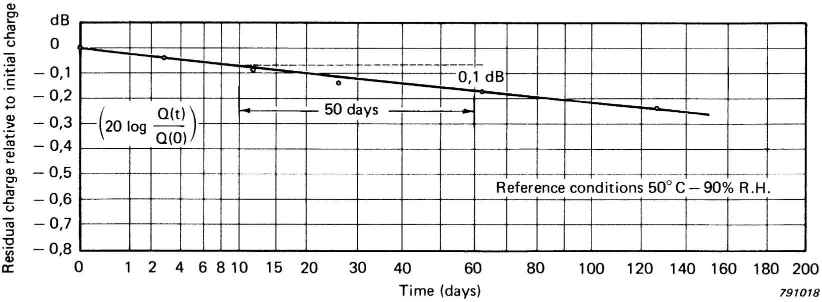

Fig.11. Charge or sensitivity decay as a function of time at 50°C and 90% R.H. After 10 days the charge decay is typically less than 0,1 dB in the following 50 days

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*) The diaphragm is that part of the mechanical construction which dominates the long-term stability, as its internal tension tends to decrease with time. Artificial ageing and stability results have been discussed in B & K Technical Review No. 2, 1969.

crease as the square root of the time, i.e. with a factor of ten for an increase of exposure of 100 times. After 10 days of ageing, a typical unit will change less than 0,1 dB in the following 50 days (See Fig.11) or less than 0,35 dB in the following year. This is more than three times better than stated in the official specifications (< 1 dB/year).

An estimation of the influence of temperature on the rate of the discharging process at 90% RH is shown in Fig.12. It can be seen that for an environment of 90% RH, the stability is 20 — 30 times better at room temperature than it is at 50°C. At normal tropical temperatures the stability is also improved considerably compared to the reference ambient condition.

As the loss of charge is low at the reference conditions (50°C and 90% R.H.), and as any local climate in the world, averaged over the year, creates a far less critical environment, loss of charge, and thus decrease of microphone sensitivity, plays practically no role.

Thus it can be concluded that neither higher temperatures nor humidity cause loss of charge, which is important in the long run for microphones used for noise and other sound measurements in the field.

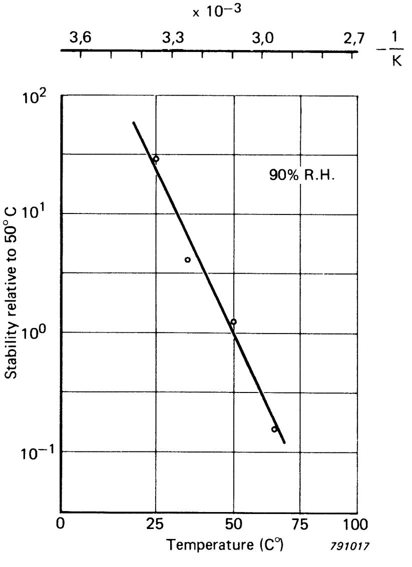

Fig.12. Stability estimated as a function of temperature at 90% R.H.

Properties obtained with Types 4155 and 4175

The new prepolarized microphones Types 4155 and 4175 correspond to the existing widely used Types 4165 and 4125, which are condenser microphones operating according to the traditional principle, i.e. they are supplied with charge from an external source.

Generally, the acoustical performance obtained for the new microphones is similar to that of Type 4165 and Type 4125 respectively, but there are some exceptions.

For practical reasons a visible difference has been made; two grooves on the cylindrical outside surface indicate that Types 4155 and 4175 operate without external polarization voltage (see Fig.13).

The microphones are negatively charged, i.e. they give a positive voltage for a positive pressure, the opposite of other B & K microphones, which are charged positively.*

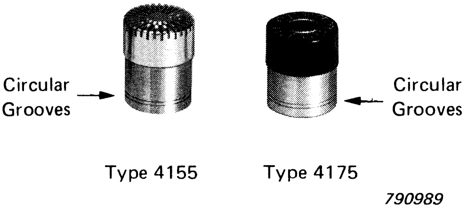

Fig.13. Photograph of Microphone Types 4155 and 4175. Prepolarized Microphones are identified by the circular grooves indicated

The effective polarization voltage corresponds to 200 V for Type 4155 and 160 V for Type 4175. This means that the voltage of Type 4155 is equal to that of Type 4165 and that both these microphones have a nominal sensitivity of 50 mV/Pa. This is also the case for Type 4175 as this microphone has a polarization voltage which is approximately 5 times higher than that of Type 4125; the nominal voltage of Type 4125 is 28 V and its sensitivity is approximately 10 mV/Pa.

As both new microphones have high sensitivity and low acoustical di-

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* No harm will be done if the microphones are connected to a + 200 V source, but generally the sensitivity will decrease by more than 12 dB and the frequency response will change. It is therefore meaningless to operate in this manner.

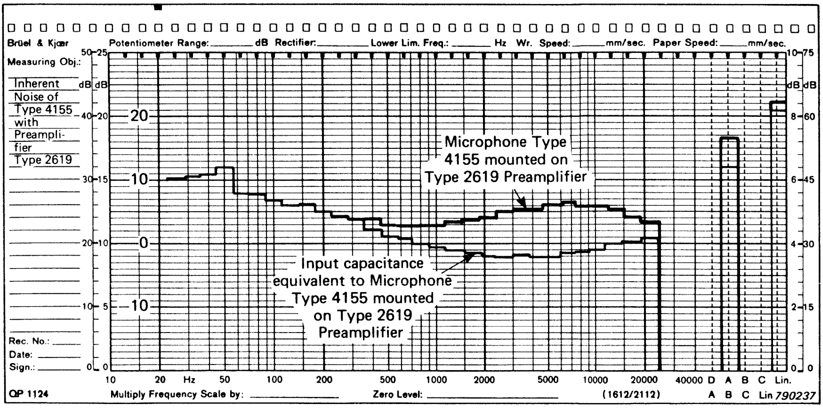

Fig.14. Third octave noise spectra for Type 4155 together with Preamplifier Type 2619. The cartridge noise spectrum is identical to that of the equivalent externally polarized microphone, Type 4165

aphragm impedance, they have excellent noise specifications compared with most other microphones of the same dimensions. Third octave noise spectra are shown in Fig.14 for Type 4155. The upper curve is valid for the complete system, microphone cartridge and preamplifier, while the lower curve is valid for the preamplifier alone when its input terminals are connected to a capacitance equal to the capacitance of Type 4155. It is seen that thermal noise caused by thermally activated movements of the microphone diaphragm is dominant at higher frequencies, while the preamplifier noise determines the noise level at lower frequencies. The cartridge noise is equal to the noise of Type 4165; however, at low frequencies the noise of the preamplifier is lower with Type 4165 because of the higher cartridge capacitance. The reason why Type 4155 has a lower capacitance is that the charge carrying element acts as a series capacitor for the air gap capacitance which is equal for both types.

Distortion in a condenser microphone may be caused by non-linearity of the physical parameters which determine the movement of the diaphragm. Another reason for distortion is the displacements of the electrical charges, which take place radially on the two electrodes (i.e. diaphragm and backplate) and also between the active capacitance which they create and the loading stray capacitance in the housing and in the preamplifier input terminals. Because of the different charge conditions in the prepolarized cartridges it might be expected that their distortion

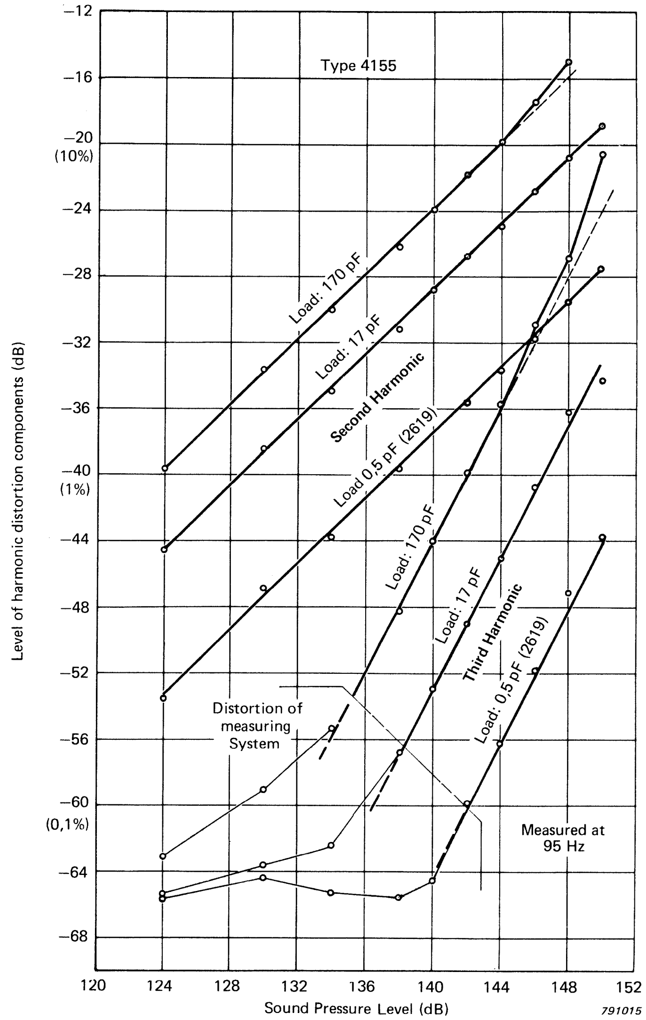

Fig.15. Harmonic distortion as a function of sound pressure level of Type 4155 (or 4165). The level and general pattern is independent of polarization principle

pattern differs from that of externally polarized cartridges. However, theoretical considerations and practical measurements such as those shown in Fig.15 verify that there is no significant difference. The distortion data given are typical for both Type 4155 as well as for the externally polarized Type 4165.

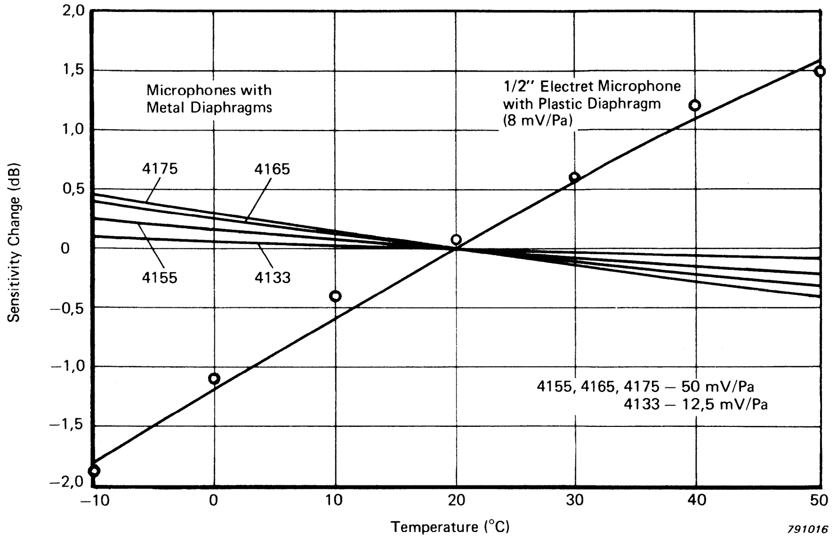

Fig.16. Sensitivity change as a function of temperature for a variety of 1/2" microphones. As is typically the case, the metal diaphragm microphones exhibit a lower temperature coefficient than plastic diaphragm microphones

The temperature coefficient at lower frequencies is slightly lower for Type 4155 than it is for Type 4165. The reason is partly thermal expansion of the electret, which slightly changes the air gap, and partly a slight increase in the electret voltage with increased temperature (approx. 0,0035 dB/°C). These effects influence the sensitivity in opposition to the dominant parameter, the diaphgram tension.

Like Type 4165, Types 4155 and 4175 have relatively high temperature coefficients compared to other B & K microphones (see Fig.16). This is a consequence of the lower diaphragm tension used for increasing the sensitivity of these 1/2" microphones from the "normal" 1/2" level (approx. 10 mV/Pa) to the level normally expected for 1" microphones (approx. 50 mV/Pa). The housing of the Type 4175 is made of german silver in order to reduce production costs; this gives a slight increase in the temperature coefficient.

An example of the temperature coefficient of an earlier commercially available 1/2" plastic diaphragm electret microphone is also shown in Fig.16. It can be seen that its sensitivity changes somewhat more with

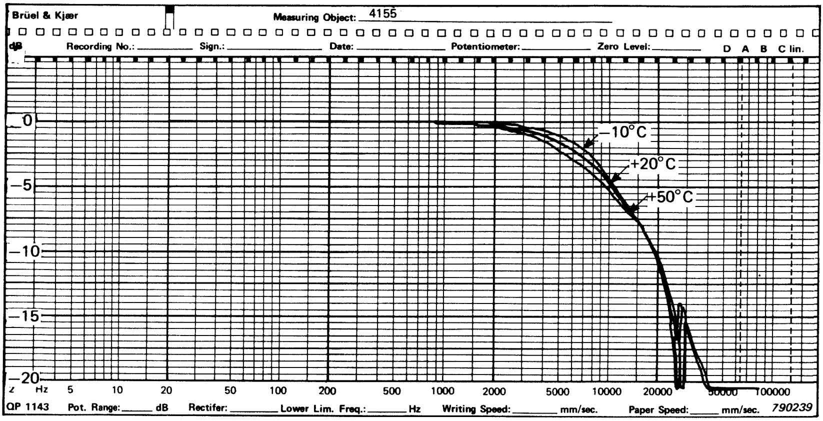

Fig. 17. Pressure frequency response of Type 4155 at different temperatures. (When used in a free field, the microphone has a flat response)

temperature than is the case for Type 4155. However, for a technical evaluation of plastic diaphragms observed from a design point of view it should not be compared with Type 4155, but rather with the B & K Type 4133, because Type 4133 has approximately the same sensitivity as the plastic diaphragm microphone. This clearly demonstrates one of the benefits of using a metal diaphragm.

Fig. 17 shows how the pressure frequency response of Type 4155 changes with temperature. The change has increased a little compared to Type 4165 but it is still of the same order; the main physical explanation for the changes is that the intended damping of the diaphragm resonance, which is dependent on the viscosity of the air in the airgap, varies with temperature. Compared to 1/2" microphones with high diaphragm tension, these changes appear at lower frequencies because of the lower diaphragm resonance frequency which is a consequence of the high sensitivity chosen for the microphone.

The complexity of Type 4155, which is greater than that of Type 4165, has made it necessary to extend the tolerances for the frequency response at the upper limit of the frequency range above 15 kHz, however, it is still clearly within the limits of the type 1 requirements of the newly published IEC Standard no. 651 which only specifies the frequency response to 12,5 kHz. This recommendation also specifies a type 2 sound level meter. As the tolerances of that have been tightened compared with the older specifications given in IEC recommendation 123, the Type 4175 has been designed to comply with the new ones.

In connection with the development of Type 4155 a new protection grid has been designed, giving improved protection against contamination of the diaphragm. The grid has a built-in fine stainless steel wire mesh, which at the actual frequencies for Type 4155, i.e. below 20 kHz, has very little influence on the frequency response. This grid is also going to be used with the Types 4165 — 4166 in the future.

Generally, it may be concluded that the new microphones correspond to well established microphones in the B & K program and that, from an acoustical point of view, they do not offer any added possibilities.

It should also be noted that these new microphones are more expensive to produce simply because of the added element carrying the charge and the costs related to its careful treatment.

Generally, it is expected that electret microphones can be produced more cheaply than ordinary condenser microphones, but of course it is an incorrect assumption which may have arisen because of the many cheap nonprofessional electret microphones which are available today. Most of them are perfectly designed for their purpose, but design compromises have been made which are unacceptable for measuring microphones. Any construction detail or material which might be used for lowering the production costs of prepolarized microphones could also be used for microphones with external polarization. Therefore it is clear that a prepolarized microphone cartridge implies higher production costs than a conventional condenser microphone cartridge of corresponding design and quality.

So far it may appear that the disadvantage of added cost of prepolarized microphones is the main difference between the two versions of condenser microphones, but in the following some advantages will be discussed.

Advantages Related to Types 4155 and 4175

In the prepolarized microphones, the external polarization voltage source has been substituted by the internal charge carrying element. This means that a simplification of the associated electronics can be made. Sensitive microphones normally need a polarization voltage of 150 V to 200 V; this voltage is usually generated in a measuring amplifier or a sound level meter and supplied to the cartridge via the preamplifier circuit. To obtain a low noise floor of the preamplifier, ripple and hum must be reduced by filtration to a very low level, and in cases where the voltage is not used for other purposes, and thus not directly available, for instance in battery operated equipment, it must be generated only for this purpose. Costs are therefore saved in preamplifier and power supply when a prepolarized microphone is used. In each case the system designer has to evaluate if the savings cover the extra costs of a prepolarized microphone cartridge. Even if that is not the case, there may be other reasons for choosing a prepolarized microphone.

Because of the increasing interest and legislation within noise abatement and hearing protection there is a growing need for smaller transportable sound measuring instruments for survey purposes. Such instruments, which should preferably fit in the pocket, must be small; therefore the space saving achieved by omitting a DC-converter for polarization voltage generation may be important.

Furthermore, it is important to save power on practically all battery operated equipment; another reason for eliminating the converter. This is especially the case for instruments with relatively long operation intervals, for instance, in the measurement of L_{eq} and noise dose.

In connection with the design of sound level meters and preamplifiers, the relatively high polarization voltage requires special attention. A small leakage in the circuits or in their components, which might be caused by humidity, together with the 200 V potential and the high impedances present in the preamplifier, may cause impulsive noise which would make low level measurements impossible unless special cleaning and humidity protection techniques were being used. Systematically performed climatic tests have shown that electret microphones make it possible to use simplified procedures for protection treatment of circuits.

As seen, there may be a number of advantages which, in each case, the system designers have to evaluate in relation to the drawbacks, which are mainly connected with the added production costs.

Failure Mechanisms

Operational failures may appear in prepolarized microphones as well as in ordinary condenser microphones. Statistical examinations have shown that the most common microphone cartridge failure is mechanical damage of the protection grid and thus in most cases also of the diaphragm; obviously it happens because microphones and preamplifiers, or sound level meters, are dropped or struck by accident by the users. Therefore one might wish for a more rugged grid but as the microphones have to comply with certain standards, and as in many cases they are used for even more accurate measurements than standards require, the freedom in the design of the protection grid has been limited for acoustical reasons.

After simple mechanical damage which, because of the same mechanical design, is equally likely for the two versions of condenser microphones, corrosion of pin holes in the diaphragm plays a role. For design reasons, the diaphragms must have a very low mass and thus be very thin, which tends to increase the problems related to corrosion; therefore the B & K microphone types which are most often submitted to critical environments have special corrosion protection layers on their diaphragms. This is the case for Type 4155 as well as for Type 4165 — their diaphragms are protected with a quartz layer of 0,6 μm thickness. Years of practical use and experiments carried out in the laboratory with Type 4165 have proved the effectiveness of the protection layer. High temperatures and high degrees of humidity are parameters which, combined with high concentration of particle contamination, form a critical environment, especially for unprotected microphones.

The quartz layer added to protect the diaphragm absorbs small amounts of humidity which gives the two microphones Types 4155 and 4165 a sensitivity which is slightly dependent on the humidity of the ambient air (see Fig.18). For Type 4175 a layer of chlorosulphonated polyethylene is used instead of quartz.

An added insurance against the risk of that kind of damage may be obtained by using foam windscreens, which are especially recommended in heavily polluted areas; their efficiency has been proved in practice under extremely critical environmental conditions,i. e. within the area of a large chemical plant and at other places.

Pinholes, which may appear as a result of the corrosion, open the way for humidity and for the formation of corrosion products inside the critical air gap of any condenser microphone, including prepolarized microphones. The electrical field strength is of the order 100,000 V/cm for most condenser microphones independent of polarization principle. Any particles in the gap, and thus also the corrosion products, may lead to arcing. When occurring, this arcing causes impulsive noise. The energy

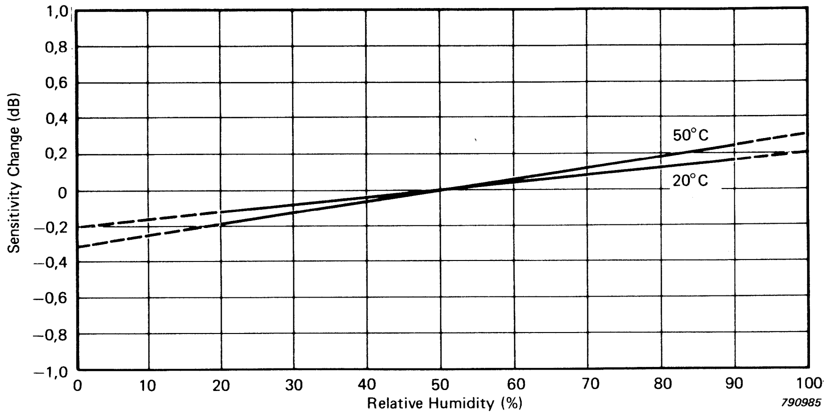

Fig. 18. Change in sensitivity of Type 4155 (and the externally polarized Type 4165) as a function of relative humidity. The effect is due to moisture absorption in the protecting quartz layer on the diaphragm

which is released in this manner is taken from the electrical field. When an external source is connected, the charge will be rebuilt and the arcing may continue for some time, possibly until the cartridge has been dried by heat or by a silicagel container, after which the cartridge may operate perfectly again.

However, for prepolarized microphones, the corrosion products at the pinholes may lead to a permanent local loss of electret charge. In fact, the built in charge is not lost, but charges of opposite polarity, possibly formed during arcing, may settle on top of the charge - containing layer and they may neutralize a number of the frozen charges, so that the field in the gap is reduced. The reduction leads to a permanent decrease in sensitivity of the cartridge.

Attention should be paid to the two different ways in which the microphone versions may fail; however, the protection arrangements made with the cartridges and the additional precautions which the user may take in critical environments (use of foam windscreens and dehumidifiers) ensure a high reliability of both microphone versions for a long time.

Incidental noise problems might be expected to appear for a condenser microphone due to condensation of water in the air gap when it is moved from a high temperature environment with high humidity to a low temperature environment.

Therefore a series of tests was made with five different microphone Types, including Types 4155 and 4165; each Type was represented by five new units. In the first part of the experiment the cartridges were moved one by one from an environment of 23°C and 90% RH to 0°C, while the noise of the microphone cartridges was monitored. In the second part, the microphones were moved from 40°C, 90% RH to 23°C. The conditions were chosen to simulate the most critical change which could be experienced when going outdoors, or when leaving a car, with a microphone in a temperate climate location, and when going into an air conditioned room in a tropical location. The microphones were moved to an enclosure where the noise level was low enough so that any increase of the noise floor of the system was detectable. For Types 4155 and 4165 it was approximately 16 dB(A) and 24 dB SPL when measured linearly between 20 Hz and 20 000 Hz. For none of the different microphone types, including all units of Types 4155 and 4165, was it possible to detect any additional noise. Furthermore, no loss of charge could be detected for Type 4155. A charge loss of 0,07% would have been detectable. As mentioned previously, this experiment was carried out with new microphones.*

Conclusion

Two prepolarized microphones have been designed; their general specifications comply with other B & K condenser microphones, so from an acoustical point of view they do not extend the measurement range of the program.

As is generally the case, these prepolarized microphone cartridges involve higher production costs than corresponding externally polarized cartridges which are of the same mechanical quality.

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* As this experiment is reported here it should also be added that old and frequently used 1″-microphone cartridges have been found which show **incidental** noise in connection with temperature **transients**. Although a detailed explanation is difficult to give, it seems clear that the effect is caused by corrosion defects which, in the cases in question, were found in the diaphragm foils. However, it should be noted that operational problems of that kind may be avoided in many cases if a foam windscreen is mounted on the microphone before the microphone is submitted to the colder environment. The explanation may be that the microphone housing is then cooled down before the diaphragm and that the condensation of moisture from the internal cavity now occurs on the non-critical internal wall of the housing and not in the critical gap between the diaphragm and the backplate.

The charge-carrying element which has been developed has a quality corresponding to the other stability-determining parameters of the cartridges, so it does not limit the specifications given for the cartridges in high-temperature environments. Additionally, with respect to humidity there will be no limitations in practical use even under tropical conditions.

The advantages obtained by application of the prepolarized microphones are most significant in the design of sound level meters, preamplifiers and power supplies. They can be made cheaper, smaller, use less power, and may be more reliable in humid environments.

Precautions have been taken, and additional ones may be carried out by the user, which will improve the reliability of both versions of condenser microphones, irrespective of the polarization principle.

It is expected that, in future prepolarized condenser microphones will be used for many general sound and noise measurements. For the time being there seems to be no particular reason for developing prepolarized microphones for laboratory measurements, and even less as laboratory standard microphones for calibration purposes, where simplicity of design is of great importance.

Impulse Analysis using a Real-Time Digital Filter Analyzer*

by

R. B. Randall & N. Thrane

ABSTRACT

Measurements of energy spectra of transient signals are much easier performed using digital analysis, compared to more traditional analog methods. Using a sonic boom as an example the paper discusses the advantages of real-time digital filter analysis and compares the various averaging modes.

SOMMAIRE

Les spectres d'énergie des signaux transitoires se calculent plus aisément par filtrage numéurique qu'en suivant les méthodes analogiques plus traditionnelles. Cet article discute, en s'illustrant de l'exemple d'un bang sonique, des nombreux avantages de l'analyse par filtrage numérique, puis compare les différents modes d'intégration.

ZUSAMMENFASSUNG

Energiespektren transienter Signale können — verglichen mit herkömmlichen, analogen Methoden — wesentlich einfacher mittels digitaler Analyse gemessen werden. Der Artikel behandelt am Beispiel des Überschallknalls die Vorteile der Echtzeit-Digitalfilter-Analyse und vergleicht die verschiedenen Methoden der Mittelwertbildung.

Introduction

A real-time 1/3-octave analyzer based on recursive digital filtering has been found to have many advantages over its all-analog predecessor, even though its fundamental operation is comparable [1] These advantages are even more marked in the analysis of impulsive or transient signals, the main reasons being connected with the digital detection

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* Paper presented at Internoise 1979, held in Warsaw, Poland

which naturally accompanies the digital filters. In short, this digital detection allows the choice of either linear or exponential averaging over a wide range of averaging times with no inherent errors or crest factor limitations. The combination of digital filter and digital detector is thus superior to other alternatives based on analog filters and detectors or analog filters and digital detectors. In many situations it is also preferable to the other major digital analysis technique, viz. FFT, because it allows the analysis of long transients over a very wide frequency range.

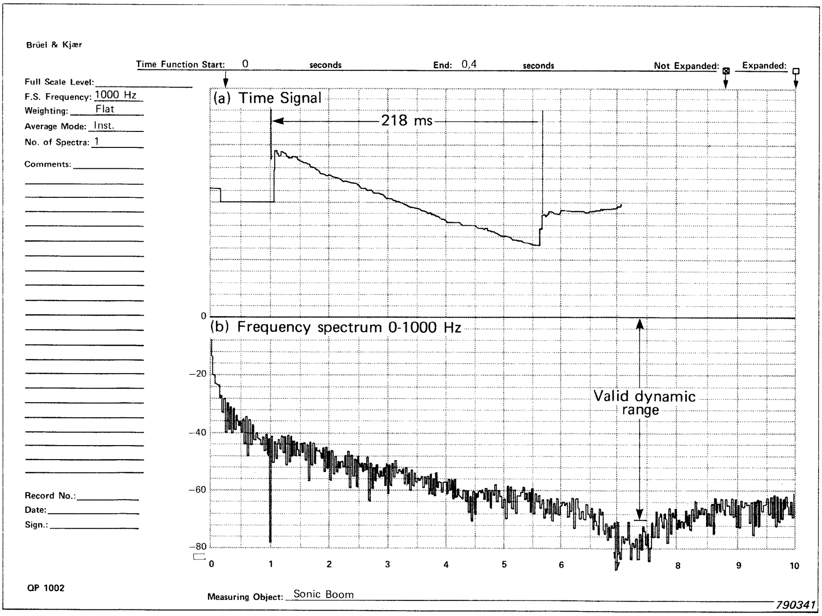
In this paper, these points are illustrated using a sonic boom as the basic signal.

Impulse Analysis

It is interesting to trace the path of a signal through a typical analysis system, analog or digital, consisting of filter, squarer and averager (integrator).

The length of the output from the filter can be considered as the sum of the original impulse length T and the filter response time T_R ($\approx 1/B$ where B is the filter bandwidth). For $T << T_R$ (i.e. at low frequencies for constant percentage bandwidth filters) the filter output will resemble its impulse response, while for $T_R << T$ with an N-wave (sonic boom) input the output will be 2 bursts of length $\approx T_R$ separated by T. The filter output is then squared, and since this is done numerically in the all-digital analyzer there is no limitation given by crest factor per se. Most analog squarers give errors for crest factors greater than a certain amount (e. g. 5 for the B & K Type 3347). On the other hand analyzers using analog filters followed by digital detectors usually "under-sample" at the higher frequencies and thus give errors with impulsive signals. For example, a typical mean sampling frequency is 1 kHz (1 ms spacing) and since T_R at 20 kHz is $\approx$ 0,2 ms, impulsive signals can be entirely missed by this type of detector. In the digital filter analyzer, the sampling theorem is obeyed in both filters and detectors at all frequencies, and thus no information is lost [2].

Finally, the squarer output must be integrated over a suitable averaging time T_A which includes all the energy in the filter output. This would ideally be a linear integration over, say, $T + 4\,T_R$ but such a linear integration must be initiated just prior to the arrival of the impulse and thus cannot be done in real-time. The impulse must either be recorded and played back with a suitable trigger inserted on another channel, or use must be made of a delay line. The ideal solution would be a running linear integration followed by a "Max. Hold" circuit, since the maximum value (when the entire filter output signal is within T_A) would be the equivalent of starting a linear average at the right time. However, in practice running linear averaging is almost impossible to achieve, and so considerable use is made of running exponential averaging which in many cases gives equivalent results. Although an exponential integrator falls at a (maximum) rate of 8,7 dB/T_A, the resulting error can be made negligible (< 0,5 dB) for $T_A > 10\ T_E$ where T_E is the "effective filtered impulse length" [3]. In this case $T_E \approx T + T_R$ as explained previously. Note that the ratio T_A/T_E may be limited in the other direction by crest factor considerations, and in that case T_E can be considered as $\approx 2\ T_R$. Thus with analog detectors it is not always possible to satisfy both requirements, while for digital detection only the first needs to be taken into account. Note that the peak output of an exponential averager is double (+ 3 dB) that of the equivalent linear averager, and this mitigates to a certain extent the effect of the longer required averaging time. Thus the time constant with which the measured (power) results must be multiplied to convert them to energy (per bandwidth) is equal to T_A for linear averaging and $T_A/2$ for exponential averaging/Max. Hold.


Time Function Start: 0 seconds End: 0,4 seconds Not Expanded: ☒ Expanded: ☐

Full Scale Level:
F.S. Frequency: 1000 Hz
Weighting: Flat
Average Mode: Inst.
No. of Spectra: 1
Comments:

Record No.:
Date:
Sign.:

Measuring Object: Sonic Boom

Fig. 1. Sonic boom analyzed on an FFT analyzer

Fig.1. shows a measured sonic boom as captured in an FFT Analyzer (B & K Type 2031) and the equivalent 400-line (constant bandwidth) analysis up to 1 kHz. This was the highest full-scale frequency for which the entire transient (length 218 ms) could be contained in the 1K memory length (400 ms) but on the other hand there does not appear to be much energy above 1 kHz within the valid dynamic range of 70 dB. Fig.2 shows the digital 1/3-octave analysis (B & K Analyzer Type 2131) of the same impulse using 0,5 s linear averaging. This would be valid at least down to the 63 Hz filter ($T + 4\ T_R \approx 480$ ms). Because of the constant percentage bandwidth there is now seen to be appreciable energy above 1 kHz, in the range where the ear is most sensitive, and this illustrates the fact that for noise evaluation purposes the digital filter approach is superior. Fig.3 shows another analysis using a linear averaging time of 8 s. Even this averaging time is barely sufficient for the lowest frequency included (1,6 Hz, $T_R \approx 2{,}5$ s, 8 s $\approx T + 3\ T_R$). This now gives a correct result at low frequencies, but some of the high frequency information is lost because the larger averaging time reduces the dynamic range by 12 dB. This result is superimposed as a dotted

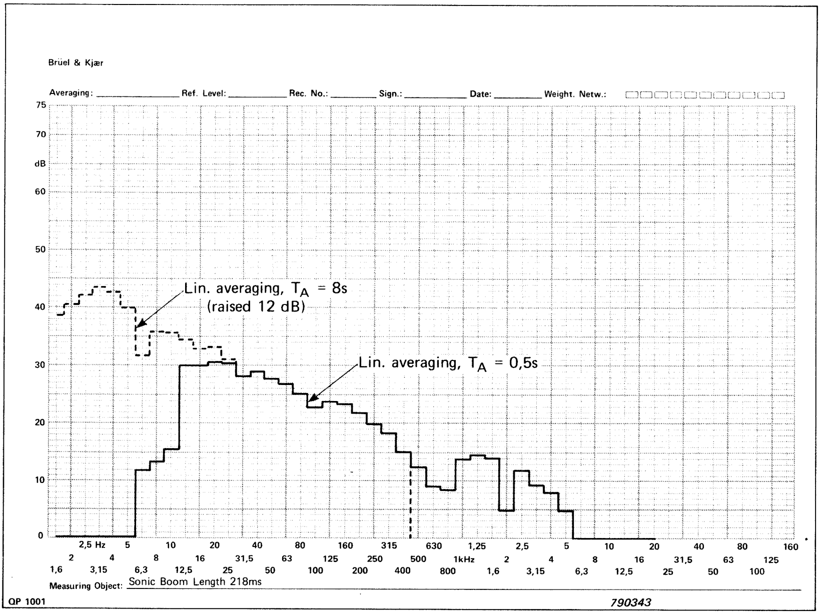


Fig.2. 1/3-octave analysis of sonic boom

line in Fig.2 (with correct scaling) and it is seen that both results coincide between 40 and 400 Hz. Fig.3 also shows the result of an analysis with $T_A = 8$ s, exponential averaging, and "Max. Hold". As expected, the result is approximately 3 dB higher at higher frequencies, the difference being reduced to 2,5 dB at the lowest valid frequency 8 Hz ($T + T_R \approx 0{,}8$ s). Finally, Fig.3 shows a 1/12-octave analysis of the same sonic boom, making use of a special 1/12-octave controller to change the filter coefficients in the analyzer. Even though this is no longer a real-time analysis, but has to be made in 4 passes, it is still valid on a non-stationary signal because the reason for the non-real-time operation is the fact that only part of the spectrum is calculated each time. The entire time record is analyzed for each of the four passes where the same recorded signal is repeatedly played back. For the same linear averaging time (8 s) the narrower bandwidth results in a 6 dB reduction of dynamic range, and moreover would only be fully valid down to 5 Hz because of the longer value of T_R. Even so the 1/12-octave analysis gives some more information about the spectrum between 5 Hz and 250 Hz. Outside this range the 1/3-octave analysis gives equally useful information in any case.

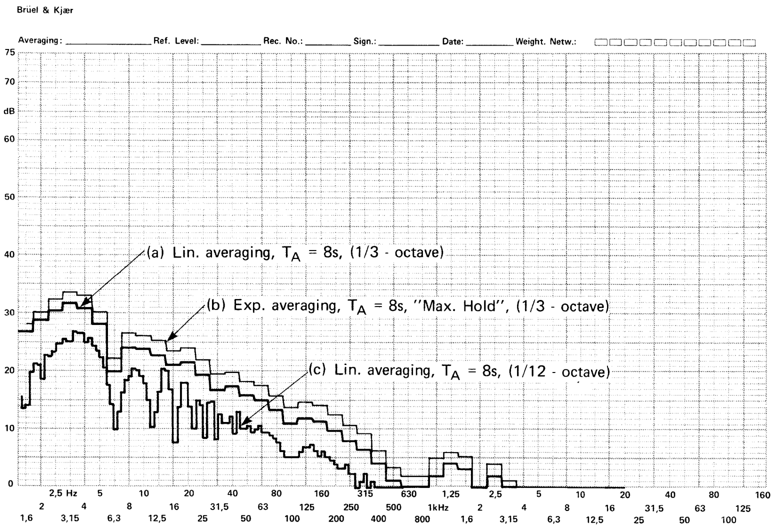


Fig.3. Comparison of analysis methods

Conclusions

A real-time 1/3-octave analyzer based on digital filtering and detection has been found ideally suited to the analysis of impulses such as sonic booms containing energy over a wide frequency range and at the same time being relatively long. The constant percentage bandwidth approach is preferable for noise evaluation purposes and would often be advantageous in evaluating the effect on physical structures whose response tends to be dominated by resonance peaks of approximately constant Q (i. e. constant percentage bandwidth).

Even though the same analyzer can obtain the whole result over 4 decades in frequency, it is difficult to achieve this in one pass. A long averaging time is required to allow for the long filter response time at low frequencies, and this reduces the dynamic range of the result. The high frequency components thus suppressed can be separately measured, however, using a shorter averaging time. Linear averaging is conceptually the easiest to use, but requires a prior knowledge of the exact time of arrival of the signal, since the averaging must be initiated in advance. For real-time analysis of randomly occurring signals, a procedure involving exponential averaging and "Max. Hold" can be used, with a slight reduction in frequency and/or dynamic range. Finally, it is also possible to make a 1/12-octave (6%) analysis with some further reduction of frequency and dynamic range, but which on the other hand can give more detail in the spectrum, for example the ability to reproduce sharper resonance peaks.

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[2] THRANE, N.: *"Analysis of Impulsive Signals by use of Digital Technique"*. SEECO 79, Society of Environmental Engineers, England

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ADDENDUM

Since the foregoing paper was written, some further measurements have been made utilizing the "constant confidence" mode of the Analyzer Type 2131 instead of constant averaging time for all channels. The feature of this mode is that the averaging time is varied for each octave so as to achieve an approximately constant BT_A product (where B is the absolute bandwidth, and T_A the averaging time for that filter). For convenience, the averaging time is held constant for all filters in each octave, and halved for each successive octave (for increasing frequency). Three BT_A products are available, corresponding to standard error values less than 0,5 , 1 and 2 dB respectively, using the formula

$$\sigma = \frac{1}{2\sqrt{BT_A}}$$

where σ is the relative standard error in RMS values

Table 1 shows the corresponding averaging times for the three cases, against octave band centre frequency.

Octave Centre frequency (Hz)		2	4	8	16	31,5	63	125	250	500	1k	2k	4k	8k	16k
T_A (s) for various values of σ	$\sigma < 0{,}5$ dB	512	256	128	64	32	16	8	4	2	1	1/2	1/4	1/8	1/16
	$\sigma < 1{,}0$ dB	128	64	32	16	8	4	2	1	1/2	1/4	1/8	1/16	1/32	1/64
	$\sigma < 2{,}0$ dB	32	16	8	4	2	1	1/2	1/4	1/8	1/16	1/32	1/64	1/128	1/256

Table 1

In the constant confidence mode, only exponential averaging is possible, and so for impulse analysis, the "Max. Hold" procedure must be used.

The method has the advantage that by choosing a certain BT_A product it is guaranteed that the averaging time will always be a fixed factor longer than the filter response time (which governs at low frequencies). On the other hand it has the disadvantage that at some higher frequency the averaging time will become too short for a given impulse length (which governs at high frequencies). Because exponential averaging is used, the averaging time must always be greater than 10 times the original impulse length and this is a fairly severe restriction.

Another disadvantage is that the results must be separately scaled for each octave because of the varying averaging times. Even so, there are some situations where the method gives some advantage over the constant averaging time method, as the following example demonstrates.

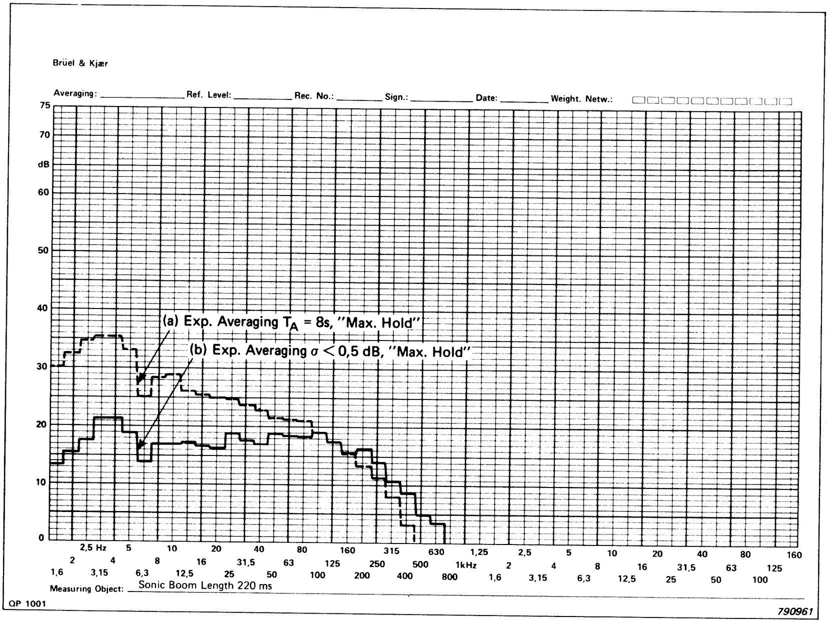


Fig.4. Comparison of results for constant T_A vs. constant BT_A product

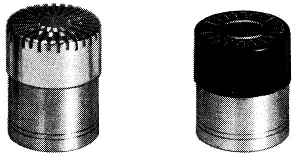
Fig.4(a) shows an analysis of a sonic boom made with 8 s averaging time (exponential averaging) and "Max. Hold" (dotted line). As previously discussed this is only valid down to 8 Hz, and it also falls below the dynamic range above 400 Hz. Fig.4(b) shows an analysis of the same signal made with $\sigma < 0,5$ dB. As expected this coincides in the 125 Hz octave band, but differs by 3 dB per octave on either side of this band. The highest valid frequency would now be 630 Hz ($T_A = 2$ s in the 500 Hz octave band and this is nearly 10 × the impulse length).

It happens that this is also the highest frequency with a measurable result, but this compares with 400 Hz for the other analysis (Fig.4a). Note that in the 400 Hz band, the difference is only 5,5 dB as against the predicted 6 dB, because the 2 s averaging time of Fig.4b is on the borderline and would only give a peak value 2,5 dB above the equivalent linearily averaged result, compared with the 3 dB difference to be expected with the 8 s averaging time of Fig.4a. On the other hand, at low frequencies, the averaging time is more than adequate right down to the lowest measured frequency of 1,6 Hz, and this explains the deviations from the 3 dB per octave rule which can be seen below 8 Hz. For example, at 1,6 Hz Fig.4a is only 16,8 dB above Fig.4b as against the 18 dB predicted, but in this case it is Fig.4a which is in error because the 8 s averaging time is only about 3 × the filter response time instead of the required factor 10.

Thus, in this case the measurement using the constant confidence mode has extended the valid frequency range of the results at each end (of a single measurement at least) and has the tendency to lift the higher frequency results into the dynamic range of the analyzer while suppressing the low frequency results. This flattening of the spectrum would almost always be an advantage in the common case where the spectrum to be measured falls off towards the higher frequencies. On the other hand the highest valid frequency is quite restricted by the necessity for the averaging time to be more than 10 × the impulse length.

News from the Factory

Prepolarized Condenser Microphone Cartridges Types 4155 and 4175



The B & K 1/2" Prepolarized Condenser Microphone Types 4155 and 4175 are high quality free-field microphones designed to complement the existing range of condenser microphones for accurate and reliable sound measurements. They have the same mechanical design as their equivalents (Types 4165 and 4125 respectively) from the existing range, which are polarized with an external supply, and therefore have very similar acoustic characteristics.

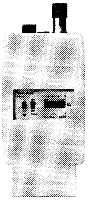
By dispensing with the external polarizing voltage there is a saving in power consumption and space and secondly there is an improvement in the performance of the associated preamplifier in humid environments. Both these factors are advantageous in the design of instruments for sound measurements in the field.

The charge carrying layer is deposited on the backplate and not, as is the case with some microphones using this principle, on the diaphragm. The long term stability is therefore as good as other B & K condenser microphones over a wide temperature range (expected to be better than ± 1 dB/40 years at 20°C in humid air at 90% R.H.). Also the temperature coefficient is kept small by this method, —0,006 (± 0,003) dB/°C for 4155 and —0,02 dB/°C for 4175 at 20°C.

The 4155 which is intended for measurements according to IEC 651 Type 1 has a free-field frequency range from 4 Hz to 16 kHz (± 2 dB) and a dynamic range from 14 dB(A) (noise floor) to 146 dB (3% distortion). The 4175 which is for measurements according to IEC 651 Type 2 has a free-field frequency range from 5 Hz to 12,5 kHz (±2,5 dB) and a dynamic range from 14 dB(A) to 144 dB (3% distortion). Both the microphones have a sensitivity of 50 mV/Pa (—26 dB re 1 V/Pa). Both microphones are delivered with individual calibration charts.

The microphones are back-vented permitting Dehumidifier 0308 to be used with the microphones in humid environments. All the accessories available for the condenser microphones may also be used with the 4155 and 4175.

Personal (ISO) Noise Dose Meter Type 4428



The Personal Noise Dose Meter Type 4428 is a completely self-contained, pocket-size unit which measures the true accumulated noise exposure according to ISO R 1999. A digital display gives continuous reading of the percentage of the allowable noise exposure to which the wearer has been subjected.

As standard a half inch microphone Type 4125 is mounted directly on the Noise Dose Meter, but if desired it can be mounted on a Microphone Preamplifier Type ZE 0300 for clip fastening near the wearer's ear. Low level detector is incorporated to inhibit measurements below 80 dB(A) as permitted by ISO R 1999. The Peak Excess Detector which is set to trigger on sound levels in excess of 140 dB(A) warns of exposure to noise of dangerously high level. It responds to noise peaks as short as 100 μs and when activated flags a "P" beside the percentage noise dose indicated on the display. Because the 4428 has a dynamic range of 60 dB including a 30 dB crest factor capability, the user can be sure of correctly registering the wide spread of noise types encountered in industry.

The 4428 has a separate "Cal." mode which boosts the count rate giving more than a 100 times faster indication to facilitate quick accurate calibration with for example The Sound Level Calibrator Type 4230. The "Cal." mode can also be used for accelerated or "short term" measurements over measurement periods substantially less than 8 hours. This is useful in extrapolating the allowable exposure time of personnel in fixed locations enabling work rotas to be planned. Using conversion tables supplied, the actual L_{eq} may be derived from the displayed % noise dose for measurement periods of 5 min, 15 min, 1 h, 2 hrs, 4 hrs and 8 hrs.

Power to the 4428 can be supplied by a single 9 V transistor radio battery, however, with a 9 V Alkaline Battery QB 0016 supplied, the overall life is approximately 70 hours for 8 hours of continuous use per day.