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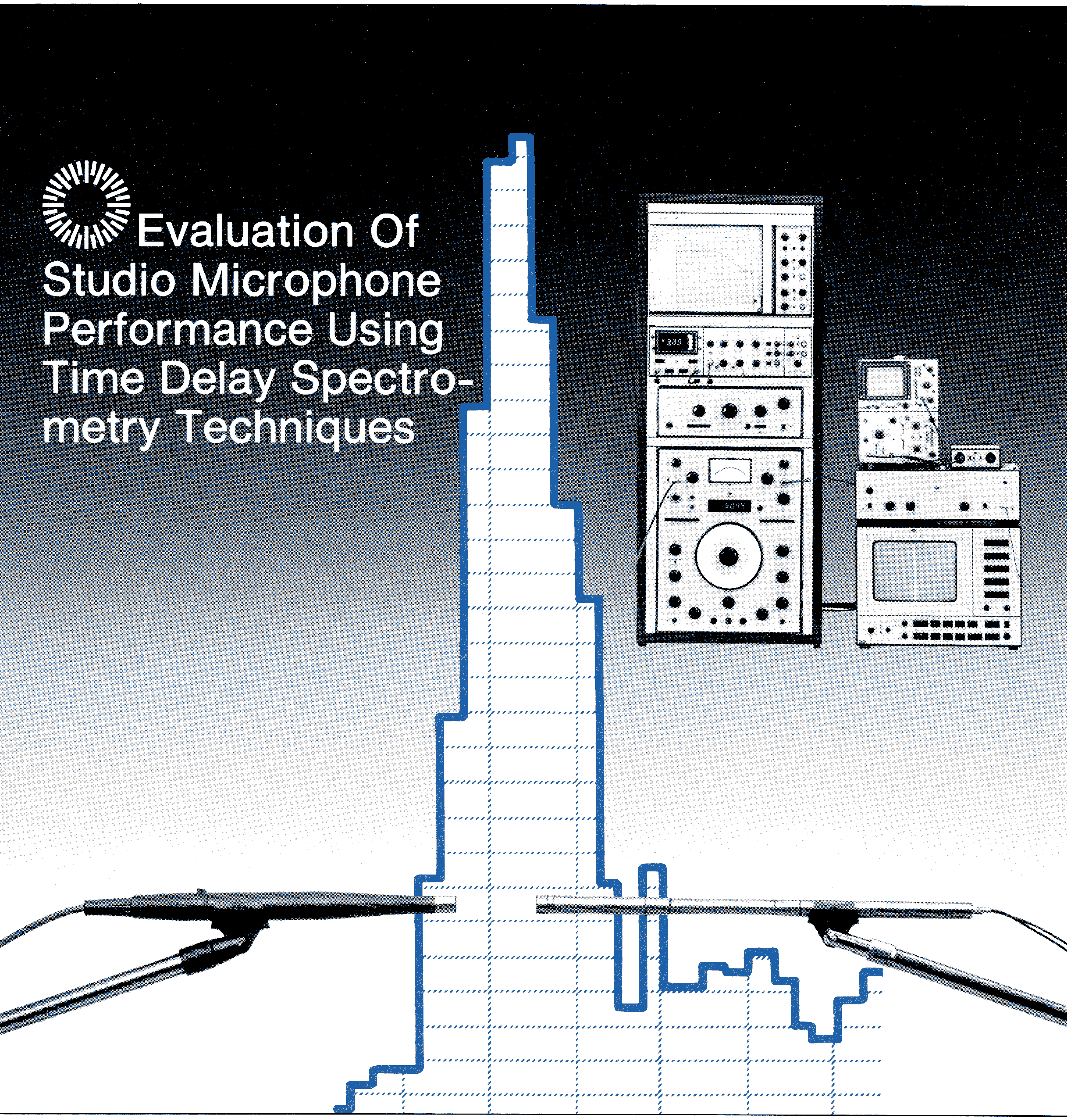
Evaluation Of Studio Microphone Performance Using Time Delay Spectrometry Techniques



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EVALUATION OF STUDIO MICROPHONE PERFORMANCE USING TIME DELAY SPECTROMETRY TECHNIQUES*

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Introduction

Microphones which are used for recording music and speech are often shrouded in mystery in terms of their electroacoustic performance and are, to a large extent, judged by professional users by their "sound" only. In most instances manufacturers' data consist of typical specifications for a particular microphone type and may include characteristics such as typical frequency response curves with acceptable tolerances, directional characteristics, sensitivity, inherent noise values, etc. Such data do not necessarily yield enough information about the performance of the microphone in an actual recording situation.

The Time Delay Spectrometry (TDS) measurement method, which has been in use for several years for loudspeaker and monitoring-room measurements, is also an excellent tool for the design and evaluation of studio microphones. TDS techniques yield a comprehensive set of data which includes amplitude and phase responses, energy time curves (ETCs) and various directional characteristics. This information can be related to the performance of the microphone. Correct interpretation of anomalies in the data uncover phenomena such as reflections, standing waves in and around the microphone cartridge, and grid and housing resonances. Time Delay Spectrometry techniques also shed much light on the all-important off-axis behaviour.

When measurements are carried out on directional microphones, special attention has to be paid to the sound field. In many anechoic chambers it may still prove difficult to establish a proper free field which is free of pressure-gradient errors. The applicability of Time Delay Spectrometry has been investigated, and even in highly reflective environments, a sound field without gradient errors can be simulated.

This Application Note discusses the evaluation of studio microphone performance using TDS techniques and presents measurements of the characteristics of five studio microphone types. More specifically:

1. A Time Delay Spectrometry measurement system including special hardware for microphone testing is described. This system should be of particular interest to microphone designers and major users such as broadcasting corporations.
2. The properties and hardware of a "flat" coherent sound source for microphone testing are described.
3. TDS mappings are discussed.
4. Correlation between the objective measurement domain and the subjective "listening" domain is discussed and illustrated with measurements on the test microphones.

TDS analysis opens up a number of possibilities for editing and displaying both time and frequency domain information. This displayed data lends itself well to interpretation and can be related to phenomena that one can hear in the subjective domain.

Conventional Mapping of Studio Microphone Characteristics

Frequency Response

The frequency response of a studio microphone is normally measured in an anechoic chamber using sinusoidal test signals. The response at each frequency is averaged over a sufficient length of time for the microphone to reach "steady state".

Implication: In a conventional frequency response graph, the concept of time and delay is obscured. The graph does not reveal the extent to which the energy in the frequency band is coherently transduced with respect to time, i.e. no allowance is made for reflections, resonances and diffraction effects in and around the microphone.

Polar Response

Measurements of the directional characteristics of a microphone are normally carried out at a few fixed frequencies. The resulting polar chart shows the response of the microphone as a function of angle of incidence. At each fixed frequency the response is usually normalized to 0 dB at 0° angle of incidence.

Implication: No information about the behaviour of the microphone at frequencies other than the fixed frequencies is obtained. Any irregularities in frequency response are lost.

** Based on a paper presented at the 72nd convention of the Audio Engineering Society Oct. 23–27, 1982.*

Mapping of Microphone Characteristics using TDS

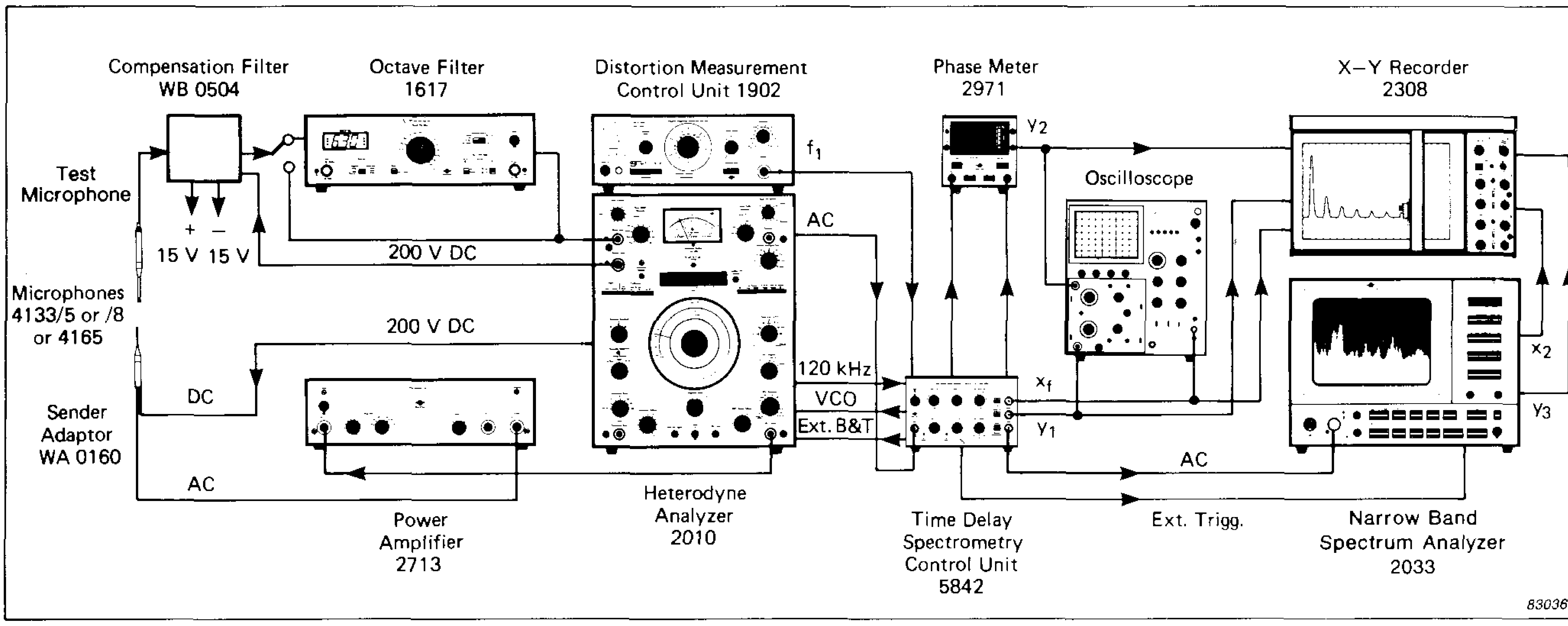

Fig. 1. Configuration of TDS system for measurement of microphone characteristics

Time Delay Spectrometry techniques offer several features which are particularly beneficial for microphone testing:

1. The sine sweep, in conjunction with a narrow band tracking filter, yields a very high signal-to-noise ratio (the test signal can be as much as 40 dB below the level of the broad-band ambient noise).
2. The analysis time is no longer than the duration of the excitation signal (typically 0,5 to 2,0 seconds).
3. Very flexible time-domain editing possibilities (segmentation).

Additional features of a general TDS system and a thorough description of TDS techniques are given in B & K Type 5842 Product Data 129-81[1].

Configuration of the Measurement System

The measurement system is shown in Fig. 1. Special features of the system are:

1. The sound source. A B & K measurement microphone Type 4133 with 0° incidence free field response from 4 Hz to 40 kHz ±2 dB was used as the transmitter[2]. This is driven by a high voltage ($100\,V_{RMS}$) Power Amplifier Type 2713.
2. The microphone under test is connected to a special de-emphasis filter WB 0504 (−12 dB/oct.) from which the signal is fed into the front end of the TDS system (Heterodyne Analyzer Type 2010).

The Band Pass Filter Type 1617 was not used in the measurements decribed herein.

The Sound Source[2]

A Brüel & Kjær Condenser Microphone Type 4133 was used as the sound source. The transmitting frequency response of this microphone, in conjunction with de-emphasis filter WB 0504, is shown in Fig. 2. The usable frequency range is from approximately 700 Hz to 40 kHz. (Using One-inch Condenser Microphone Type 4145, a frequency range of approximately 400 Hz to 16 kHz is possible.) It should be noted that it is the excellent ambient noise rejection properties of the TDS system which enable condenser microphones to be used as transmitters at relatively low frequencies where the transmitted SPL approaches the threshold of hearing (at a distance of 1 meter).

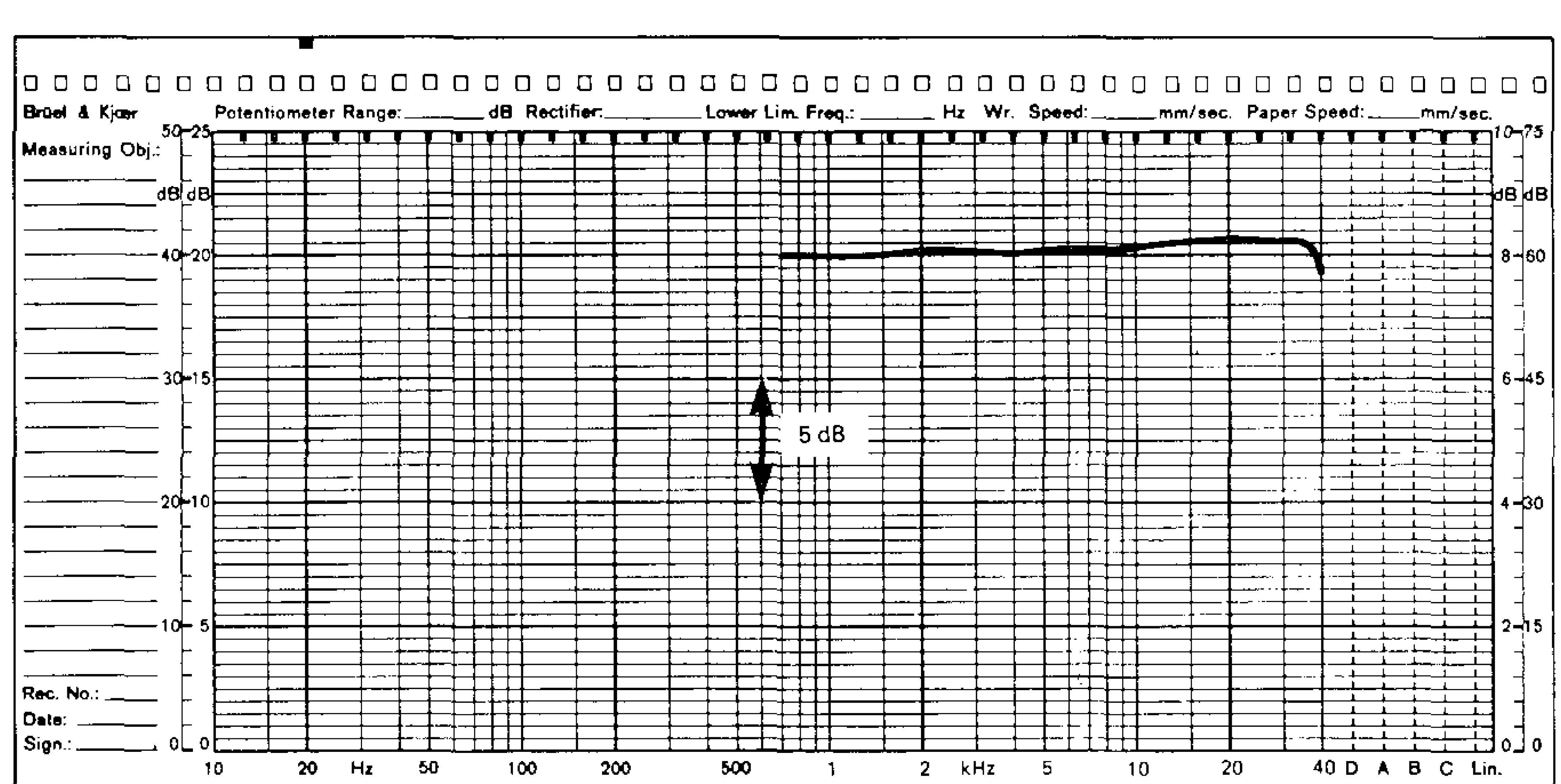

Fig. 2. Transmitting frequency response of B & K Condenser Microphone Type 4133 in conjunction with de-emphasis filter WB 0504

TDS Mapping Possibilities

A general response measurement on an electroacoustical transducer such as a studio microphone can be depicted as shown in Fig. 3. The dashed line in Fig. 3a shows the test signal which is a fast, linear sine sweep. The response of the transducer is the curve shown inside the Time Window, T, of the measurement. The Time Window is set using the TDS system by choosing an appropriate sweeprate, S, and bandwidth, B, of the sweeping filter. T is then given by the relationship $T = B/S$. B and S are chosen such that:

1. T is longer than the duration of the impulse response of the microphone under test.

2. T is of short enough duration to exclude room reflections.

Having fixed T, the frequency resolution and lower limiting frequency are given by $\Delta f = 1/T$.

Various mapping possibilities can be seen by looking at the response shown in Fig. 3a from three different directions:

1. Fig. 3b: Energy as a function of time (Energy Time Curve).

2. Figs. 3c and 3d: Amplitude and phase as a function of frequency (Complex Frequency Response).

3. Fig. 3e: Frequency as a function of time (smearing)[3].

The "ideal" versions of these curves are shown in Fig. 4. Note that the typical response curves shown in Fig. 3 are irregular (less than ideal):

1. The ETC has a finite width and is jagged (Fig. 3b).

2. The amplitude response (Fig. 3c) is not flat. The phase response (Fig. 3d) is not a straight line which passes through the origin.

3. A certain amount of frequency versus time smearing is exhibited (Fig. 3e). Smearing is not discussed in this Application Note.

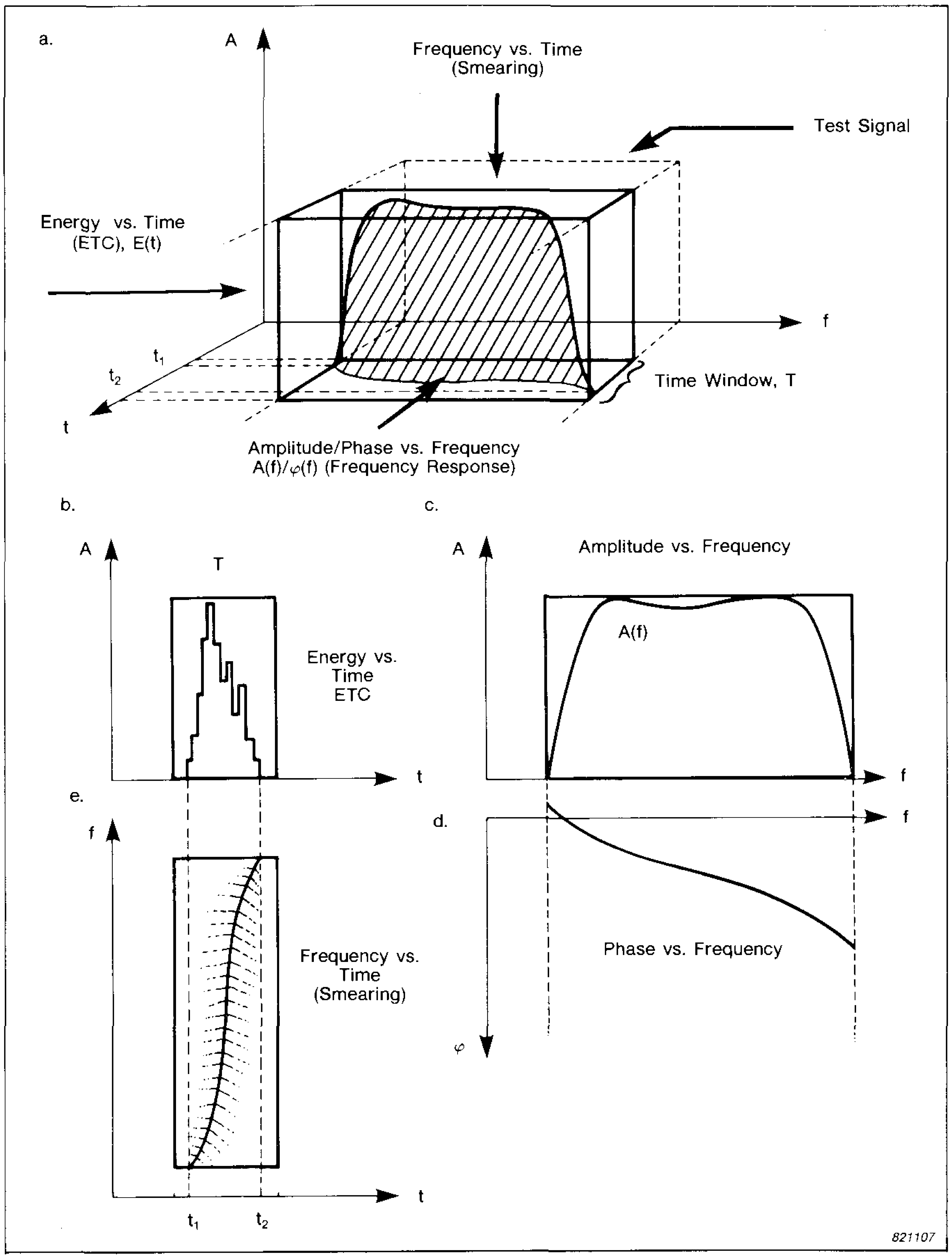

Fig. 3. Various mapping possibilities using TDS techniques

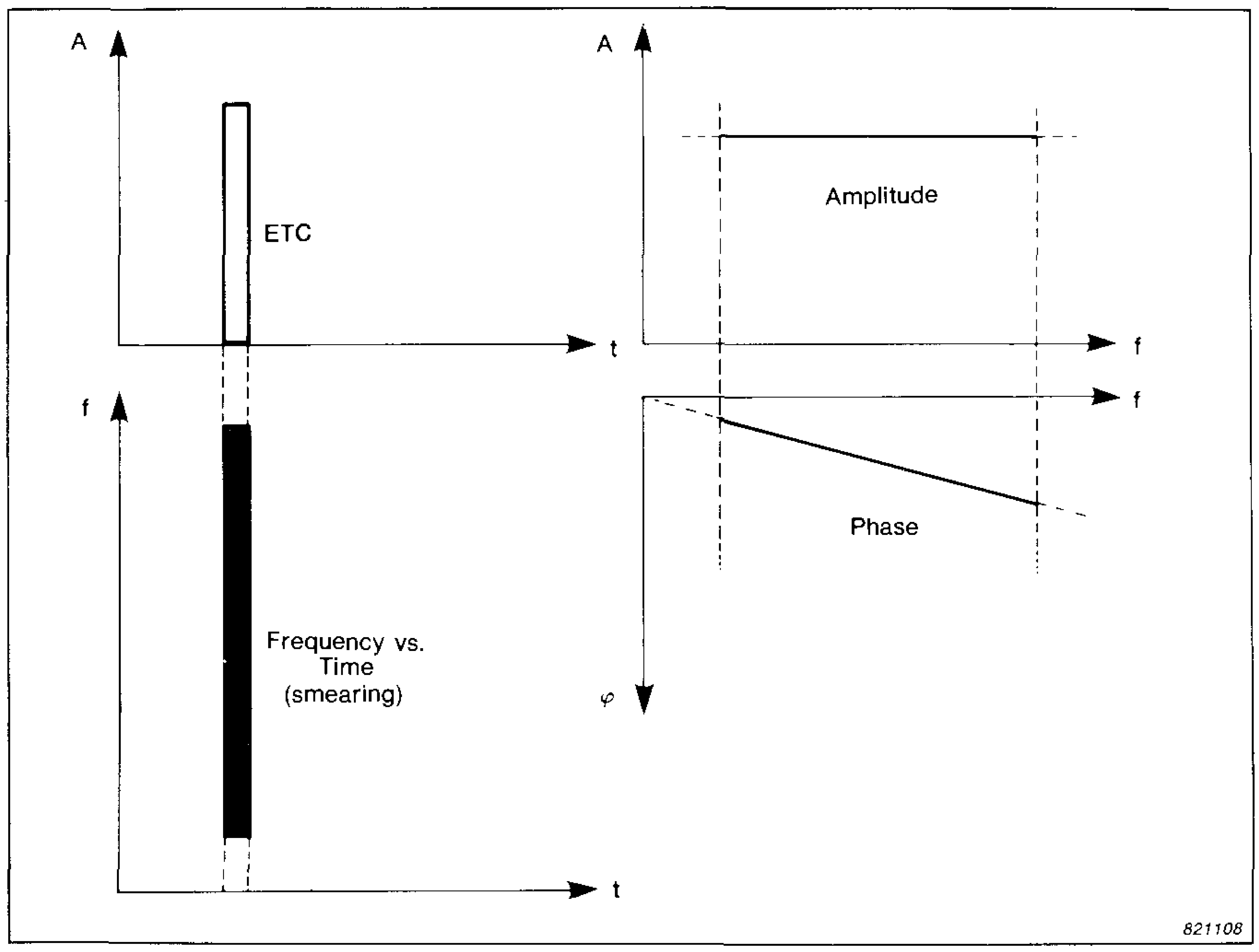

Fig. 4. "Ideal" response curves of an electroacoustic transducer

Correlation Between the Subjective and Objective Domains of Microphone Performance

There is most certainly no simple and direct link between the objective and subjective domains of microphone performance. In the subjective domain we listen to the sound image and this is judged individually and subjectively: "We each hear what we hear". When presented with a hard-copy measurement, however, we are given a set of objective data which is not as open to free and individual interpretation. Anomalies in such response data can be mapped to physically identifiable processes or phenomena such as housing resonances or reflections. We can then begin to correlate these processes with the subjective impressions we associate with the "sound" of a microphone. For example, we may be able to identify particular reflections (indicated by peaks in the Energy Time Curve) with a harsh colouration of the sound image. The various mapping possibilities that TDS techniques offer enable relations between the objective and subjective domains to be identified more easily.

In the following sections microphone performance is depicted in terms of the various TDS mappings available, and illustrations are given of TDS measurements on five different studio microphone types.

Wide-band Energy Time Curves – A Simple, Overall Description of Microphone Performance

The Energy Time Curve (ETC) is an ideal starting point in the evaluation of electroacoustic transducers. The ETC yields a straightforward indication of the manner in which a test object transduces acoustic energy to electrical energy over a given frequency range.

The commonly encountered characteristics of ETCs are illustrated in Fig. 5 together with the corresponding amplitude response in the frequency domain. Wide-band ETCs for three of the five test microphones are shown in Fig. 6. Note that test microphone *C* has selectable directivity patterns denoted by the superscript "*s*". This notation is used throughout this Application Note (e.g. cardioid^s indicates that a multiple-pattern microphone is set to give a cardioid pattern, omni^s to give an omnidirectional pattern, etc.). The frequency sweep of 0 Hz to 50 kHz is deliberately chosen so that it is wider than the frequency range of the device under test. Studio microphones typically exhibit one or more of the general characteristics illustrated in Fig. 5:

a. In the case of a band-limited microphone (Fig. 5a(ii)), a slow (wide) time response is obtained (Fig. 5a(i)).

   The subjective impression obtained is one of a "smooth", "clean" sound but one which lacks definition of transients and the ability to separate different instruments in terms of timbre and distance. An example of a band-limited microphone can be seen in Fig. 6c (Microphone *C*, omni^s).

   It should be noted that should a reflection (Fig. 5c) or a resonance (Fig. 5d) also be present, a device with a wide ETC (band-limited device) may mask these anomalies if they fall under the "umbrella" of the ETC, i.e. a microphone with an inherently narrow frequency range may mask very early reflections in the microphone and resonances of the protection grid or housing, thus diminishing the audible effects of these phenomena.

b. The ETC shown in Fig. 5b(i) illustrates an example of a transducer with a very well-defined time response arising from a wide bandwidth (Fig. 5b(ii)). An example can be seen in Figs. 6a & 6e with the corresponding frequency responses in Figs. 12a and 12b (Microphone *A*, omni).

   The subjective impression obtained is one of a high degree of definition of transients, definition of space (depth) and clear separation of instruments. Furthermore, the wide bandwidth of the microphone ensures proper tonal balance between a wide range of instruments.

c. The presence of one or more reflections in and around the microphone causes comb filter effects in the frequency response (Fig. 5c(ii)) and peaks in the ETC (Fig. 5c(i)). Subjectively this results in a harsh sound and impaired tonal resolution. An example can be seen in Figs. 6g, 11b and 13b (Microphone *C*, omni^s).

d. The resonance shown in Fig. 5d(ii) may be due to "singing" in the microphone protection grid or preamplifier housing. This causes a discrete change in the slope of the ETC (Fig. 5d(i)). Since the wide-band ETCs do not yield any frequency information, the frequency response must be consulted to determine whether or not the resonance occurs within the audio frequency range. Examples of both situations are illustrated in Figs. 11b and 12b where the resonances occur inside and outside the audio frequency range, respectively.

In general, the 90° incidence ETCs illustrated in Fig. 6 are wider than the on-axis ETCs, i.e. the microphones exhibit poorer time definition at 90° incidence than on-axis. This is due

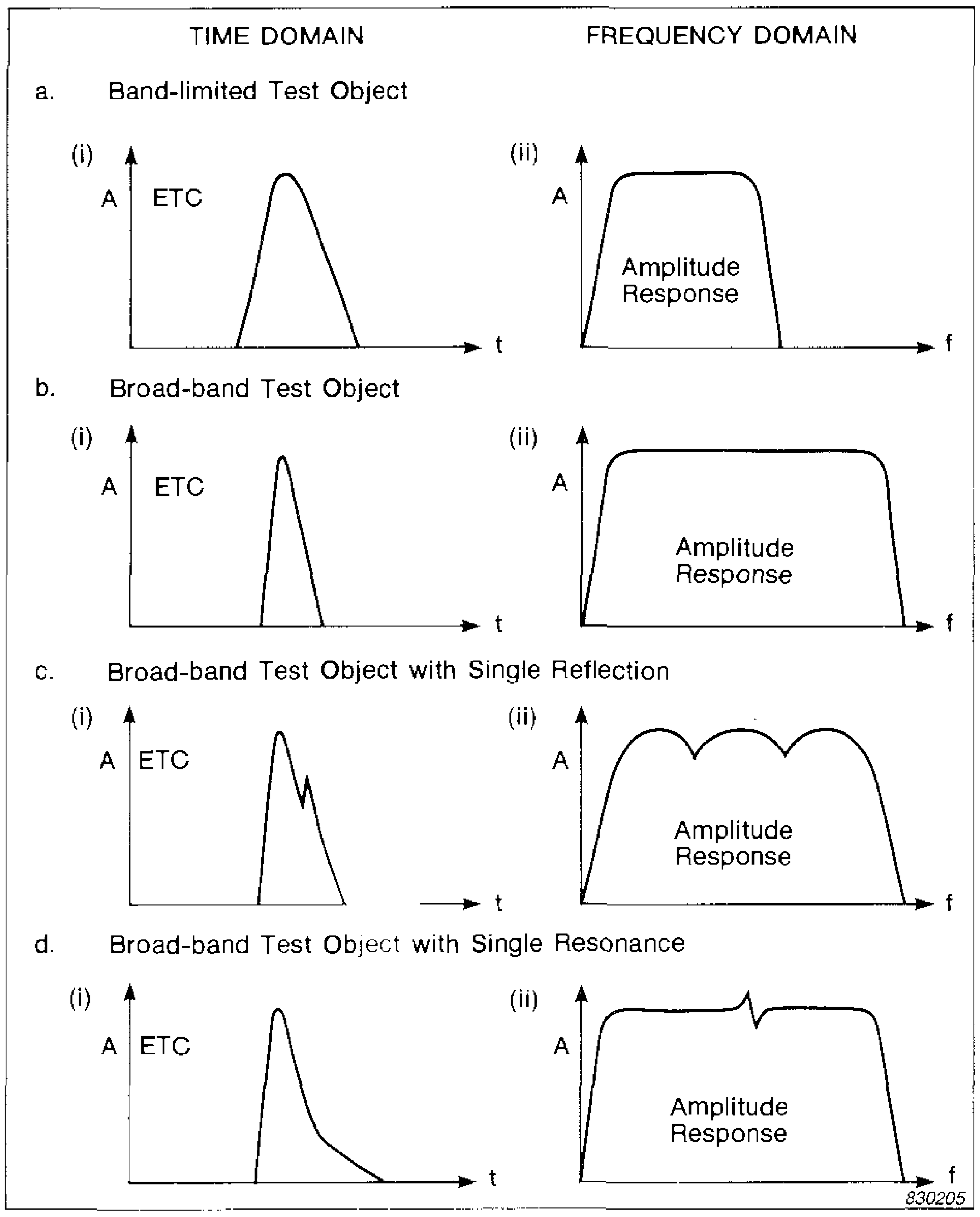

Fig. 5. General characteristics of Energy Time Curves and the corresponding amplitude responses in the frequency domain

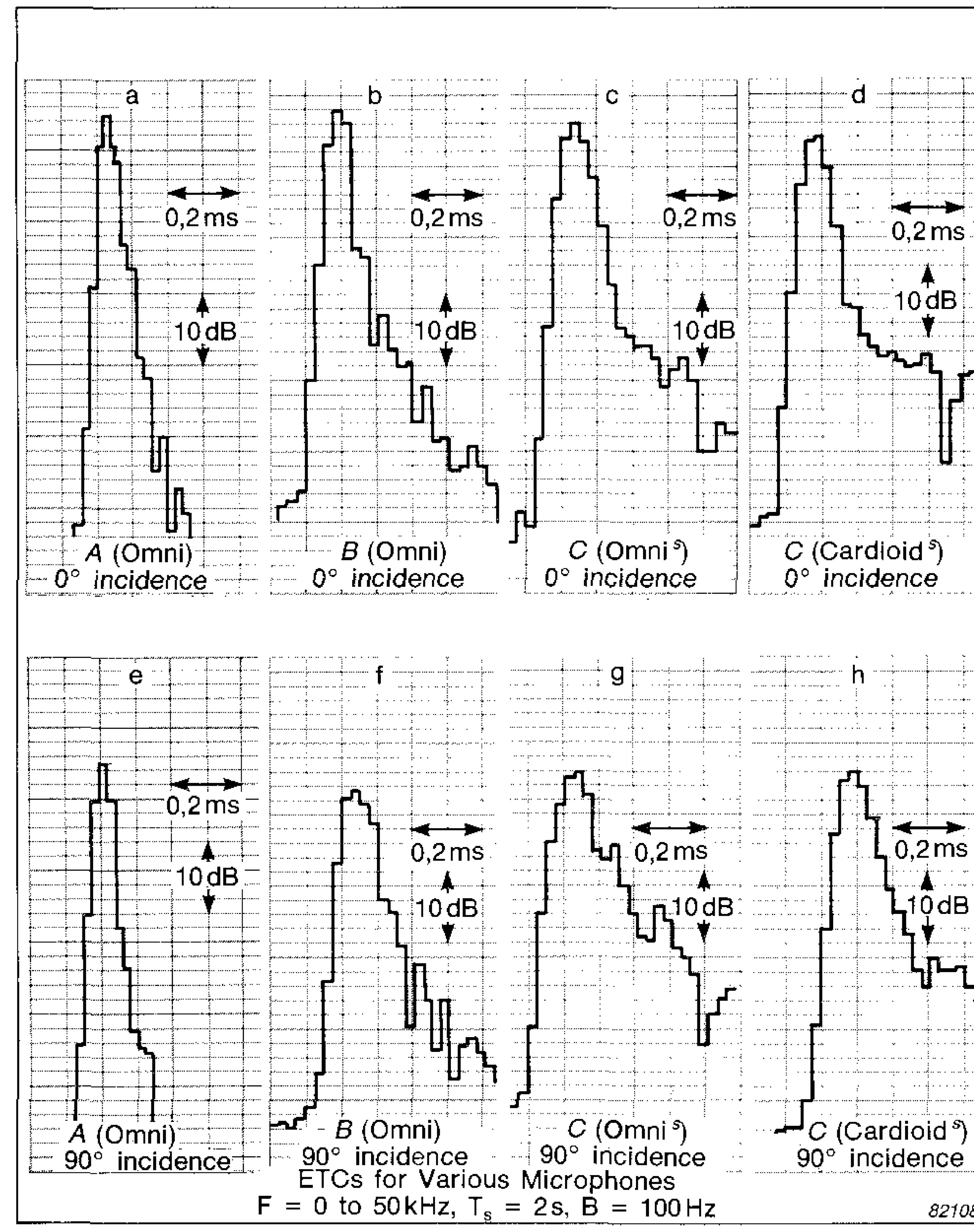

Fig. 6. On-axis and 90° incidence wide-band Energy Time Curves for Microphones A, B and C

to the width (diameter) of the diaphragm which is also the reason for the narrower frequency range at 90° incidence.

In summary, interpretation of ETCs is made by considering the following characteristics:

1. Overall Width of the ETC: A narrow ETC is indicative of a well-defined time response and a broad-band test object. Narrow ETCs indicate a "tighter", "drier" sound, wide ETCs indicate a "fatter", more smeared sound.
2. Discrete Peaks: Indicative of reflections. The effect of these reflections can be estimated by noting the number and level of the peaks. Discrete peaks indicate a harsh sound.
3. Discrete Changes of Slope: Indicative of resonances. The frequency of the resonance is found from the amplitude response. The effect of the resonance can be evaluated by noting the degree of the slope and at what level it occurs. Resonances cause colouration and smearing of the sound.

Limited-band Energy Time Curves

If a limited frequency sweep of, for example, 10 kHz is chosen, additional information can be obtained by recording a series of ETCs in overlapping frequency bands. Limited-band ETCs can be used to indicate the following:

1. To what extent the signal is coherently transduced in all frequency bands, i.e. to what extent the energy level and "overhang" (decay characteristics) are the same in each frequency band.
2. The extent of smearing (wider ETC) at 90° compared with 0° incidence in each frequency band.
3. To what extent the polar response obeys theoretical relationships:

The response of a microphone at an angle of incidence θ, relative to the on-axis response, is given by $\rho = a + b\cos\theta$, where $a + b = 1$. For an omnidirectional microphone ($a = 1$, $b = 0$) a relative output of $\rho = 1$ is obtained at all angles of incidence, i.e. there should be no off-axis attenuation. For a cardioid microphone $\rho = 0{,}5 + 0{,}5\cos\theta$, which for $\theta = 90°$ gives a relative response of $\rho = 0{,}5 + 0{,}5\cos 90° = 0{,}5$ i.e. 6 dB attenuation at 90° incidence compared to the on-axis response.

Limited-band ETCs for Microphones *C* (cardioid[5]) and *A* (omni) are shown in Figs. 7 and 8, respec-

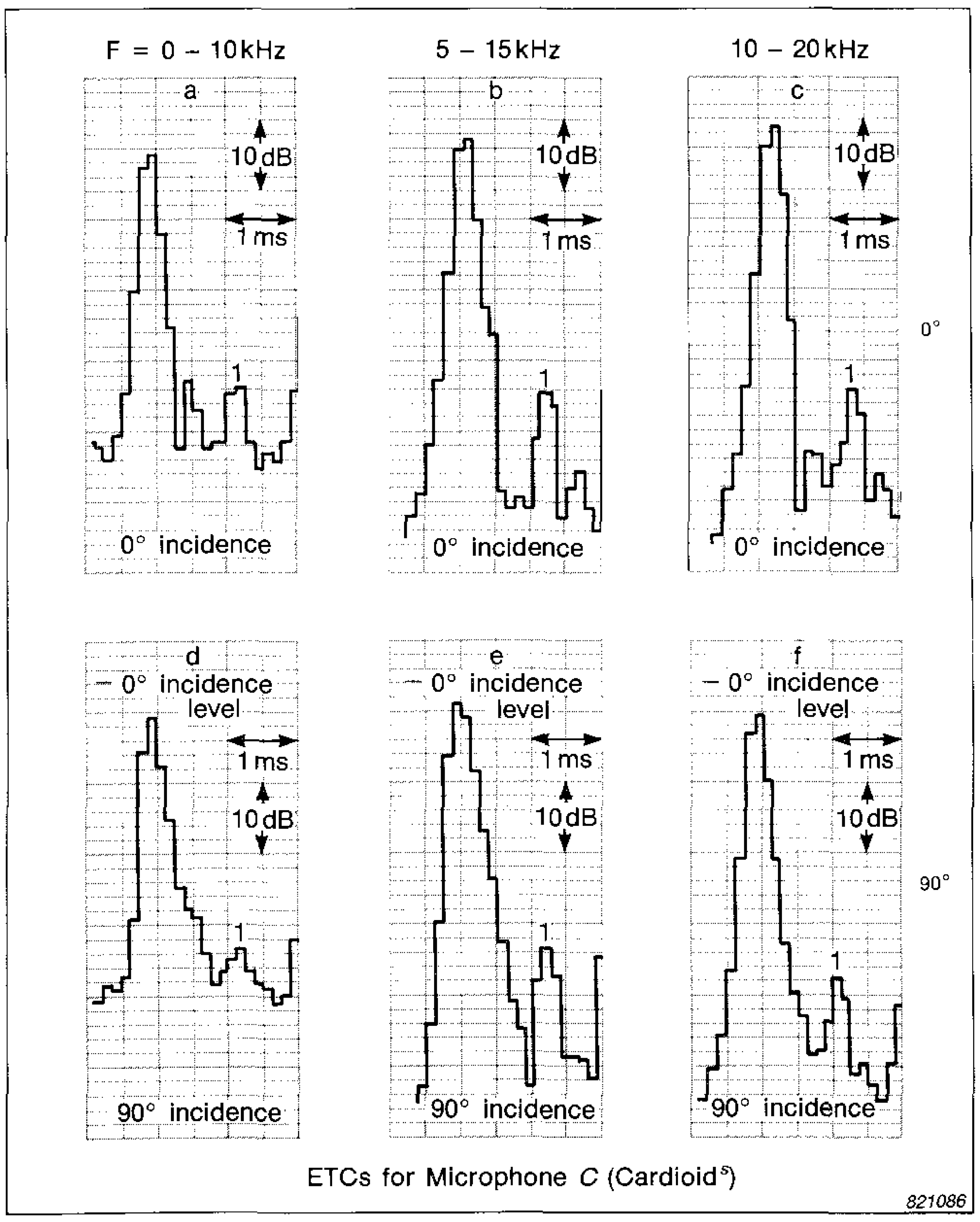

Fig.7. On-axis and 90° incidence limited-band Energy Time Curves for Microphone C (cardioid®)

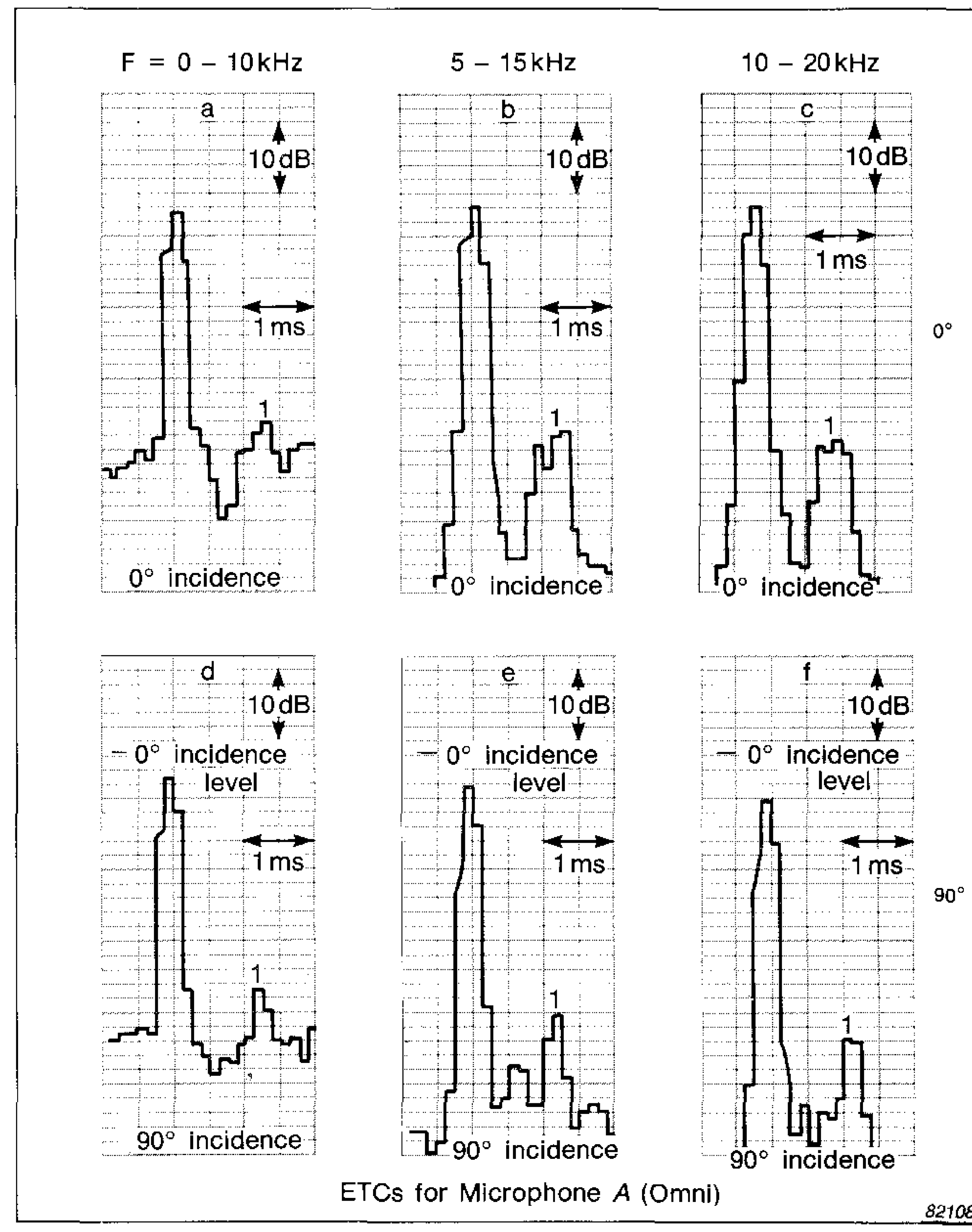

Fig.8. On-axis and 90° incidence limited-band Energy Time Curves for Microphone A (omni)

tively. The peak denoted by "1" in the figure which consistently appears at the right-hand side of the ETCs indicates a reflection from the microphone stand.

Microphone *C* (Fig. 7) gives a good cardioid response in the lower two frequency ranges with approximately 6 dB attenuation at 90° incidence, while in the range 10 to 20 kHz the response at 90° incidence has fallen by approximately 10 dB. The response of the omnidirectional microphone (Fig. 8) agrees favourably with theoretical predictions and little off-axis attenuation is evident throughout the entire frequency range. Moreover, these ETCs are narrow and there is little "ringing".

Free Field Amplitude and Phase Curves

It can be seen in Fig. 6 that the response of the microphones has rung out before 1 ms has elapsed. Choosing a suitable sweeprate, S = 25 kHz/s and filter bandwidth, B = 31,6 Hz yields a Time Window with effective duration $T = B/S$ = 1,264 ms. The Frequency Resolution obtained is $\Delta f = 1/T$ = 791 Hz. The frequency and phase responses thus obtained are an average of all the information inside the time window. 0° and 90° incidence amplitude and phase responses for test microphones *B*, *D*, *C* and *A* are shown in Figs. 9, 10, 11 and 12 respectively.

In Fig. 9a (Microphone *B*, omni) it can be seen that the "prescence hump" which peaks at approximately 7,5 kHz causes a corresponding bending of the phase curve. This results in audible distortion of consonants, which possess a lot of energy at mid-high frequencies. At 90° incidence (Fig.9b) both the amplitude and phase curves show many "wrinkles". This can be heard as a scrambling of consonant sounds.

Similar response anomalies can be seen for microphones *D* and *C* in Figs. 10 and 11 respectively. In Fig. 12 the curves exhibit far less pronounced irregularities. This is clearly evident in listening tests: Very little difference between on-axis and off-axis responses, precise timbre with no detectable colouration or over-emphasis or scrambling of consonant sounds.

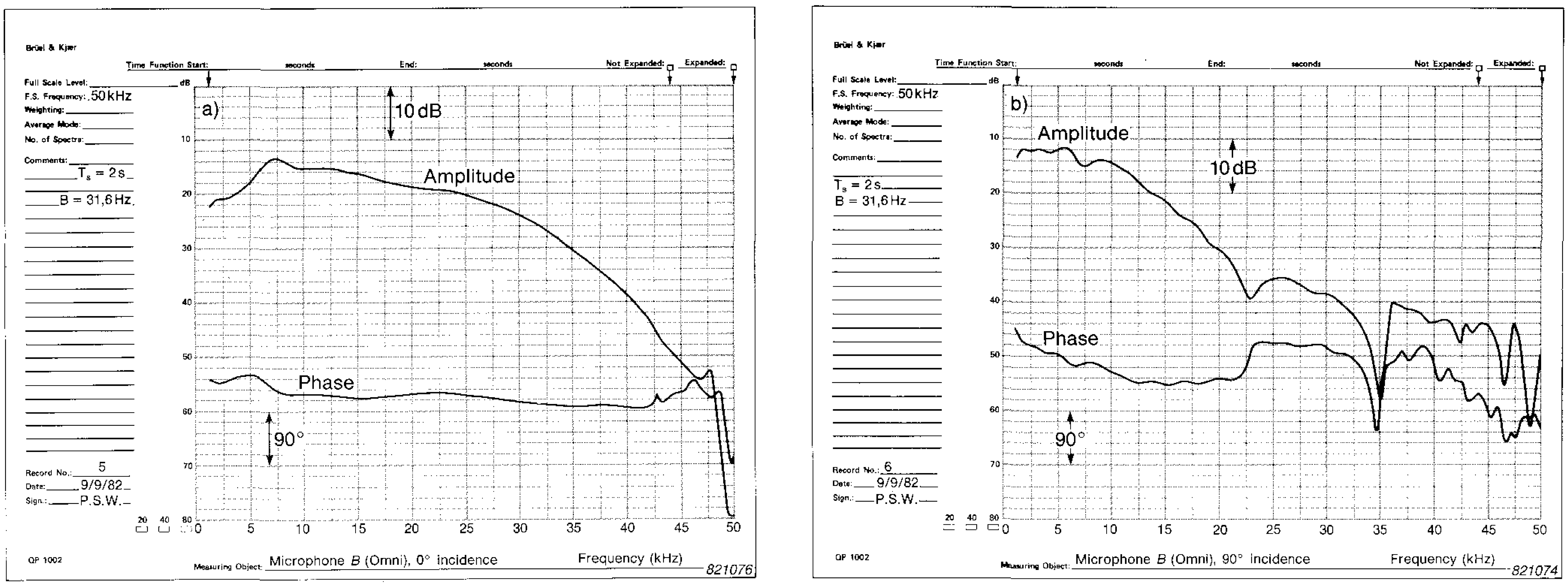

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Fig. 9. On-axis and 90° incidence amplitude and phase responses for Microphone B (omni)

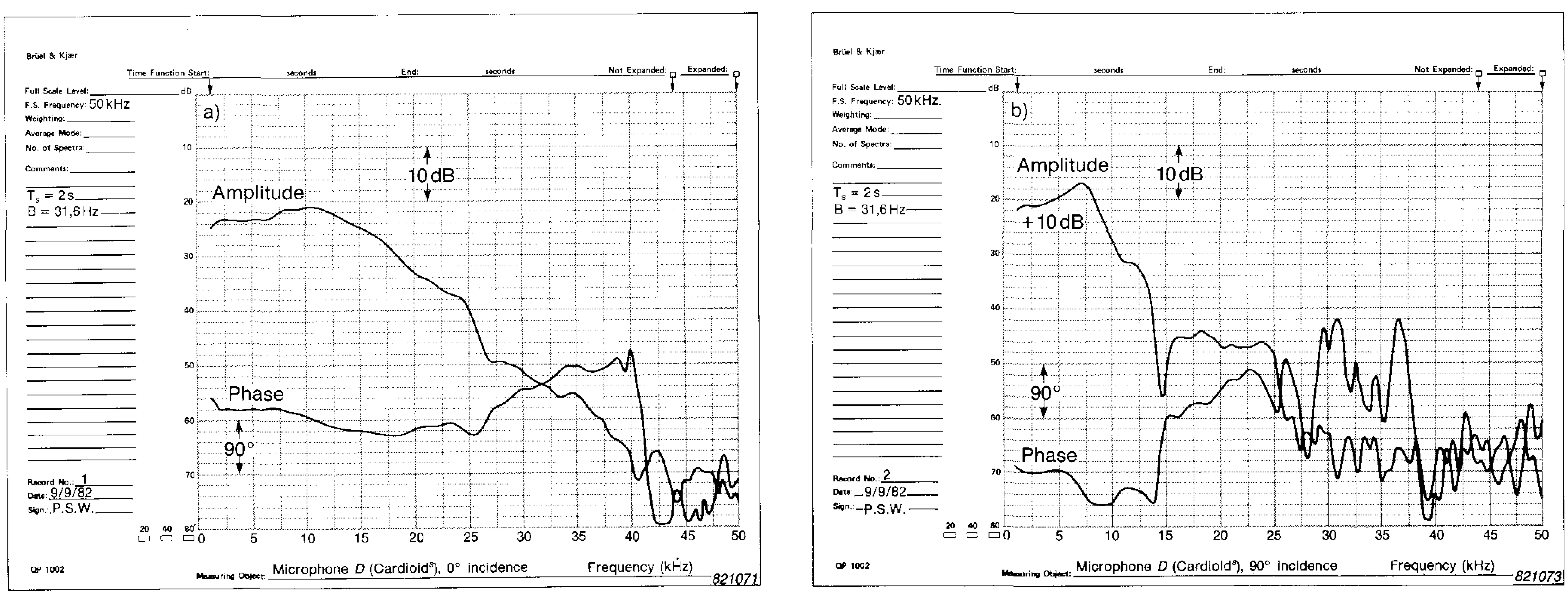

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Fig. 10. On-axis and 90° incidence amplitude and phase responses for Microphone D (cardioid^S)

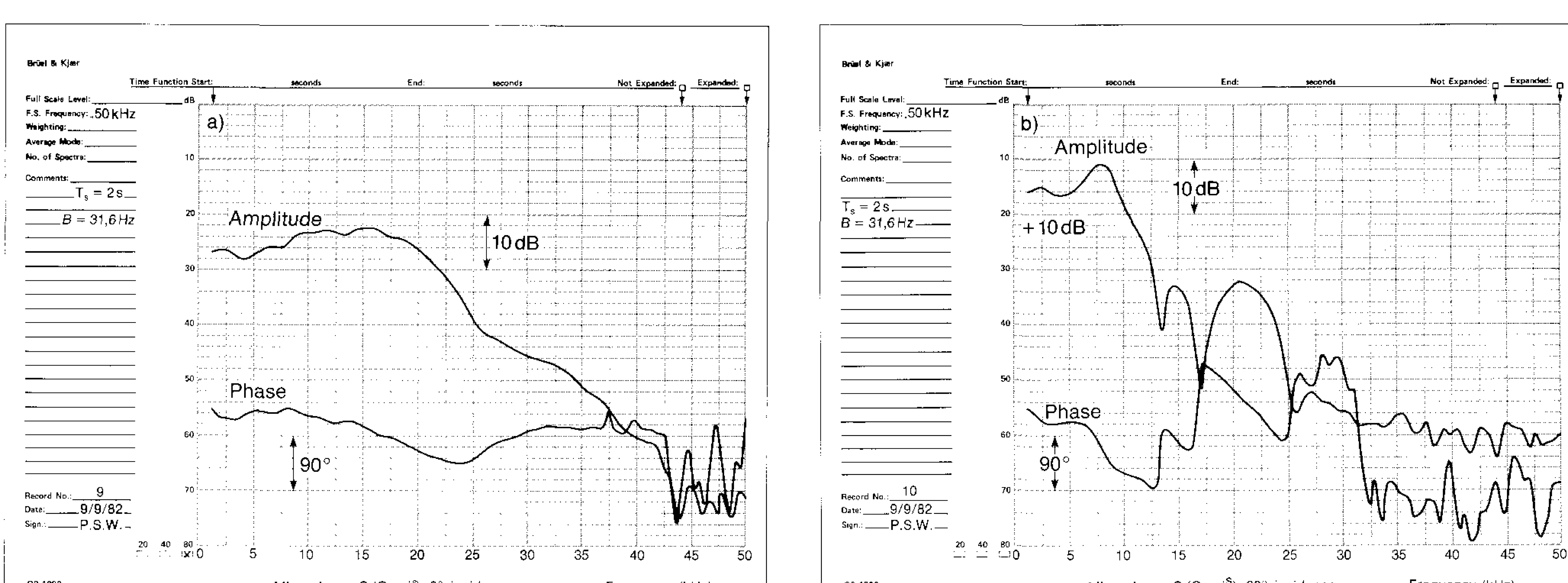

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Fig. 11. On-axis and 90° incidence amplitude and phase responses for Microphone C (omni^S)

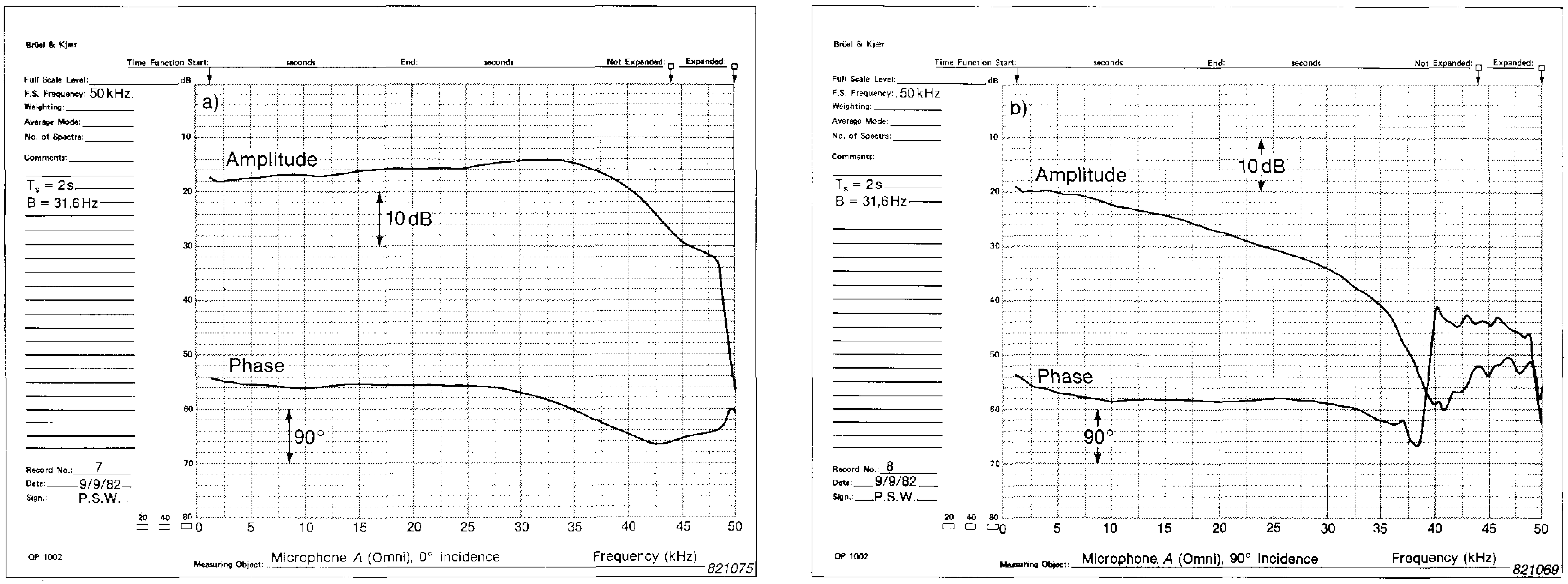

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Fig. 12. On-axis and 90° incidence amplitude and phase responses for Microphone A (omni)

Amplitude Response Curves as a Function of Time

Referring once more to Fig. 3a, it can be seen that the upper part of the response curve does not run in a straight, horizontal line from left to right owing to time smearing. Employing the very narrow filters of the FFT-analyzer (B & K Type 2033), it is then possible to slice the amplitude response into thin time sections (segmentation).

The segmented amplitude response of a multiple pattern microphone (microphone *C*) set to the omni position is shown in Fig. 13. At 0° incidence (Fig. 13a), the response centered around t_0 + 0,25 ms is 15 to 30 dB lower than at t_0 and is irregular (exhibits comb filter effects spaced 5 to 6 kHz apart), i.e. the t_0 time frame is not wide enough to allow the comb filters to build up. The time t_0 which is used here corresponds to the main peak of the ETC of the microphone. The segmented amplitude response for the same microphone at 90° incidence is shown in Fig. 13b. Here the response at t_0 shows a pronounced comb filter effect with a 10 to 13 kHz spacing. These are most likely due to the resulting pressure gradient across the plane of the diaphragm which causes reinforcement/cancellation at frequency intervals corresponding to wavelengths equal to the effective cartridge diameter. The response at t_0 + 0,25 ms is of a very high level compared to the response at t_0. Another set of comb filters with a different spacing is seen.

The segmented response of microphone *A* (omni) shown in Fig. 14 is very smooth at both 0° and 90° incidence at t_0. At t_0 + 0,25 ms a high degree of regularity across the frequency range is seen and the level is generally down 20 – 30 dB compared to t_0.

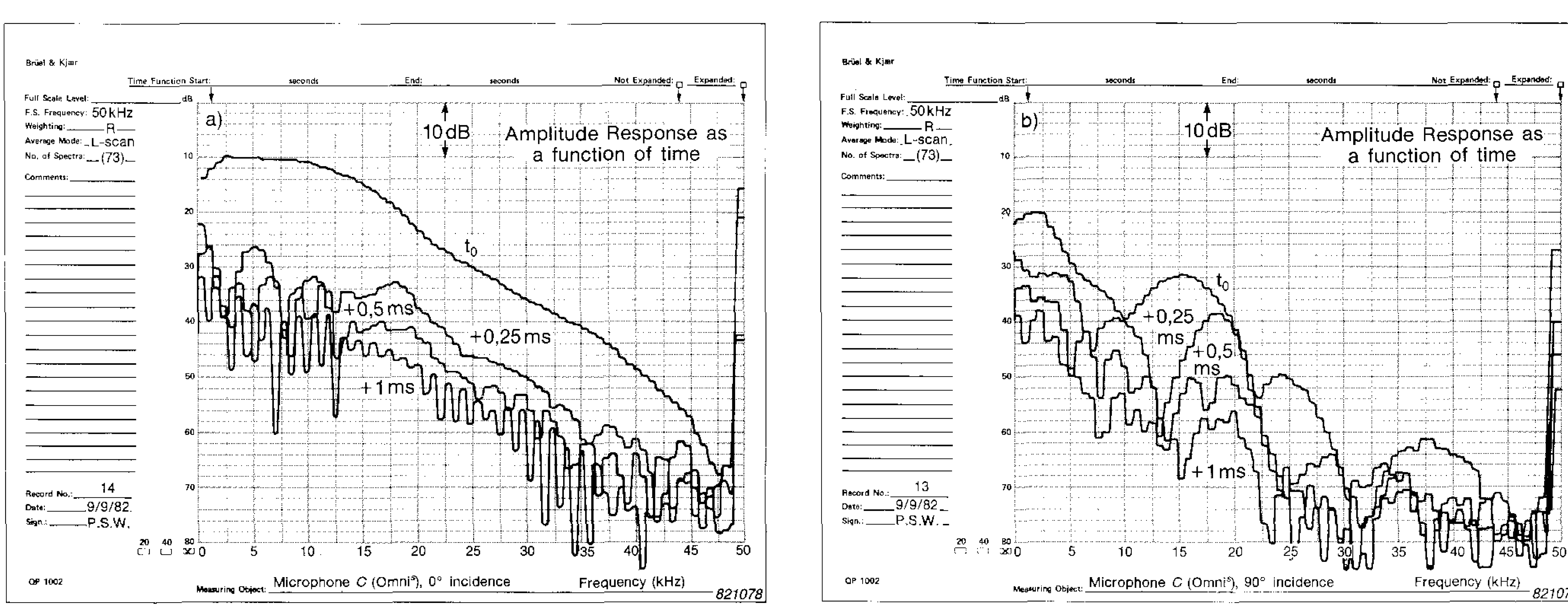

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Fig. 13. On-axis and 90° incidence segmented frequency response for Microphone C (omni S)

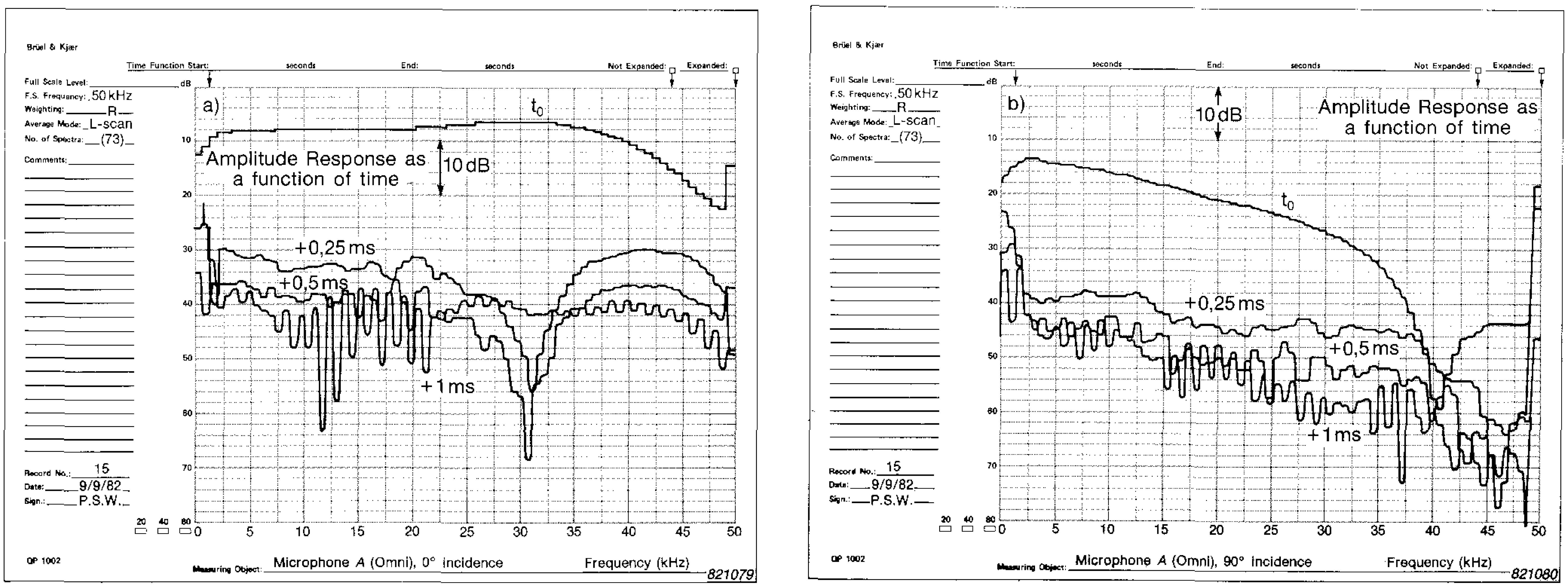

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Fig. 14. On-axis and 90° incidence segmented frequency response for Microphone A (omni)

Frequency-averaged Polar plots

The polar chart of an omnidirectional microphone with ideal directional characteristics at all frequencies consists of a set of perfect, concentric circles with identical radii. For an ideal cardioid microphone the polar chart consists of a set of ideal cardioid patterns described by the relationship $\rho = 0{,}5 + 0{,}5\cos\theta$.

Polar charts showing the directional characteristics of four of the test microphones are shown in Fig. 15. Using a standard turntable, B & K Type 3922, the polar plots were obtained as an *average* over a particular frequency band (using ETC's as a function of angle of incidence) as opposed to recording the polar response at one fixed frequency. In order not to obscure data, the reference level at 0° was *not* changed, despite the fact that the microphone had a higher or lower output at another frequency band. In this way, the overall polar performance of the microphone can more readily be assessed. The more ideal the polar pattern, the closer the patterns fall directly on top of one another. The area between the patterns, which could be called the "polar discrepancy area" should be a minimum. This method of plotting the polar response leads to a better understanding of the directional characteristics of the microphone over the entire frequency range.

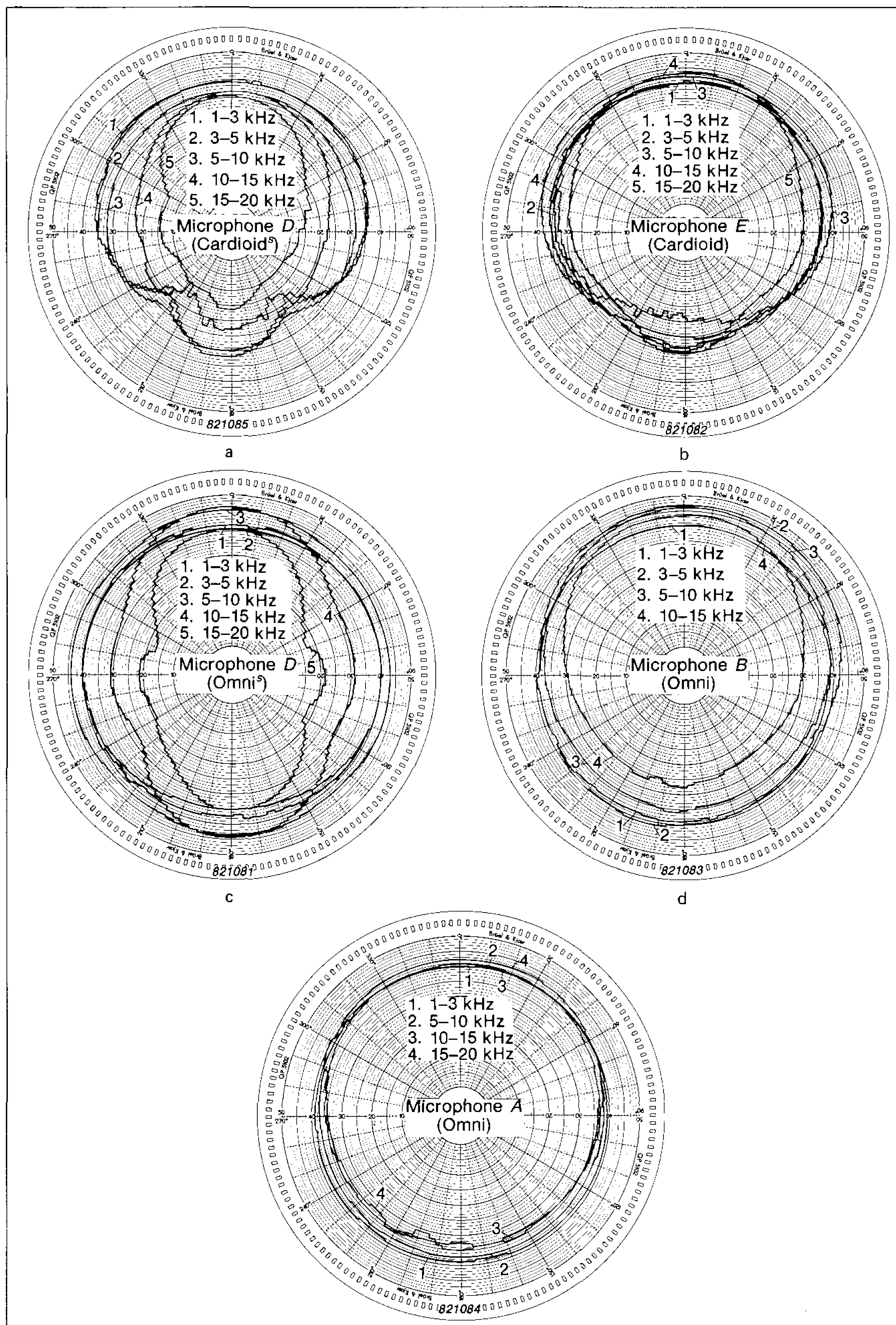

Fig. 15. Frequency-averaged polar plots

Conclusion

Microphone performance in a practical recording situation need not be based on subjective impressions of its "sound" only. The major characteristics of a studio microphone can easily be displayed using a suitable analysis technique such as Time Delay Spectrometry, thus avoiding the expensive use of an anechoic chamber. Appropriate data reduction techniques can be used to display the data in a form which is easier to relate to the performance of the microphone in the recording situation and problem areas can be assessed.

The key to good microphone response involves more than a relatively smooth amplitude response curve up to 20 kHz. The roll-off should be smooth and gradual to ensure a linear phase characteristic. The energy time curve should be as narrow as possible with only one major peak and should not have multiple slopes. This is valid for both on-axis and off-axis data in order to avoid colouration of the sound.

The energy time curve (ETC), which indicates to what extent the microphone coherently transduces acoustic energy over a broad frequency range, is a good starting point for assessing microphone behaviour on-axis as well as off-axis. The individual peaks of the energy time curves, often showing up in a periodic pattern, are indicative of reflections in and around the cartridge. The main slope of the energy time curve is a result of microphone bandwidth and dimensions, while discrete slopes can be the result of ringing in the microphone grid, cartridge and preamplifier housing.

A comprehensive polar response can be obtained by plotting the magnitude of limited-band ETC's as a function of angle of incidence, thus using the maximum amount of frequency information.

Time Delay Spectrometry techniques do not introduce any new information as such, but proper signal analysis and time editing techniques do enable much more useful information to be readily obtained and displayed.

Equipment:

B & K Time Delay Spectrometry Control Unit Type 5842
B & K Heterodyne Analyzer Type 2010
B & K Power Amplifier Type 2713
B & K Compensation Filter WB 0504
B & K Distortion Measurement Control Unit Type 1902
B & K Phase Meter Type 2971
B & K High Resolution Signal Analyzer Type 2033
B & K X-Y Recorder Type 2308
Dual Channel Oscilloscope

Sound Source:

B & K Condenser Microphone Type 4133 with Adaptor WA 0160. Transmitter characteristics as shown in Fig. 2

Test Microphones:

Microphone *A:* 12 mm diameter, omnidirectional condenser microphone with 0° incidence free field response from 20 Hz to 40 kHz ±2 dB (B & K Studio Microphone Type 4004)

Microphone *B:* 21 mm diameter, omnidirectional condenser microphone with 0° incidence free field response from 40 Hz to 20 kHz*.

Microphone *C:* 46 mm diameter, pressure-gradient condenser microphone with selectable omnidirectional, "wide cardioid", cardioid, hypercardioid and bi-directional polar responses. 0° incidence free field response from 40 Hz to 18 kHz.*

Microphone *D:* 56 mm diameter, pressure-gradient condenser microphone with selectable omnidirectional, cardioid and bi-directional polar responses. 0° incidence free field response from 40 Hz to 16 kHz*.

Microphone *E:* 21 mm diameter, pressure-gradient condenser microphone with cardioid polar response. 0° incidence free field response from 40 Hz to 20 kHz.*

* Manufacturer's Data

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