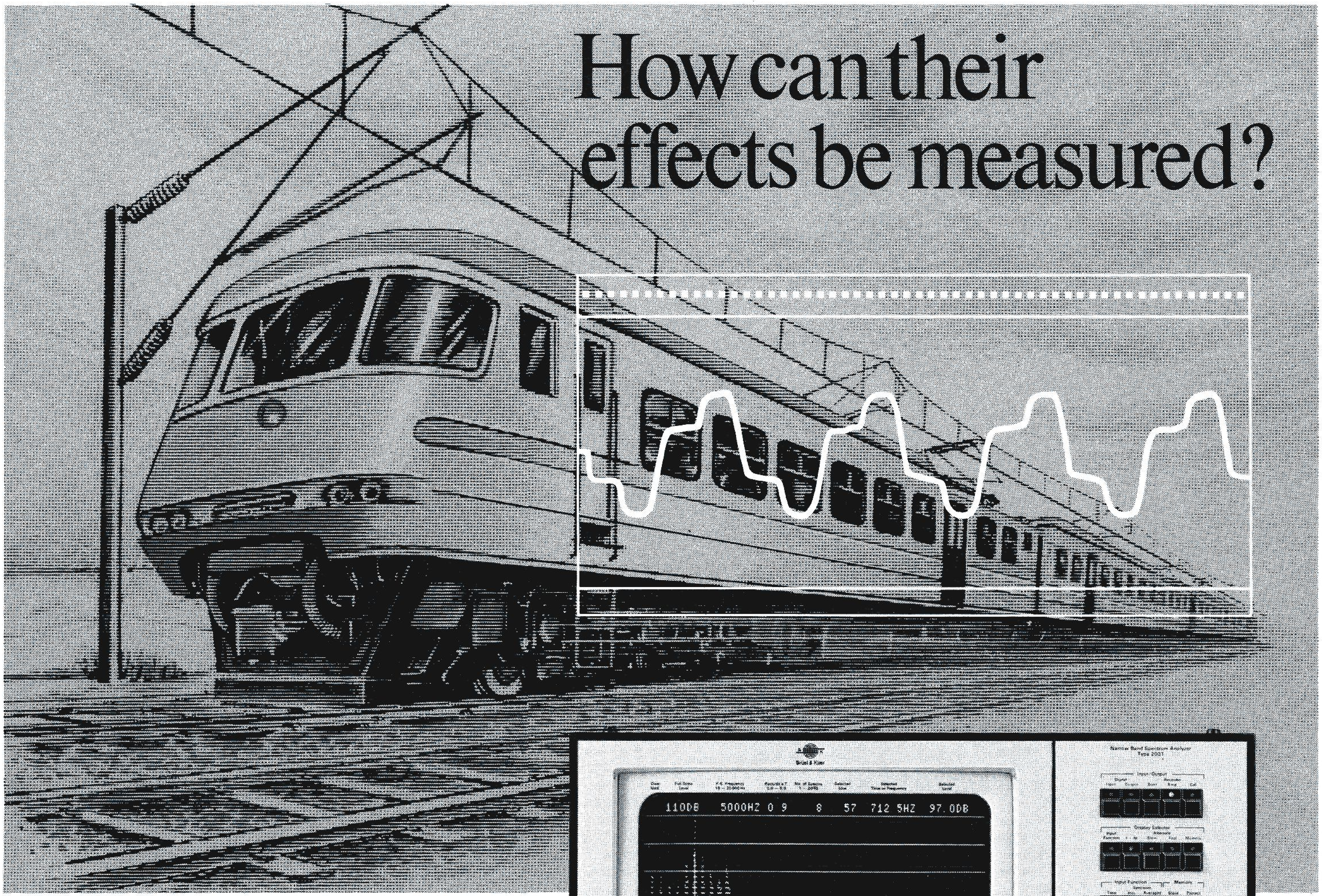
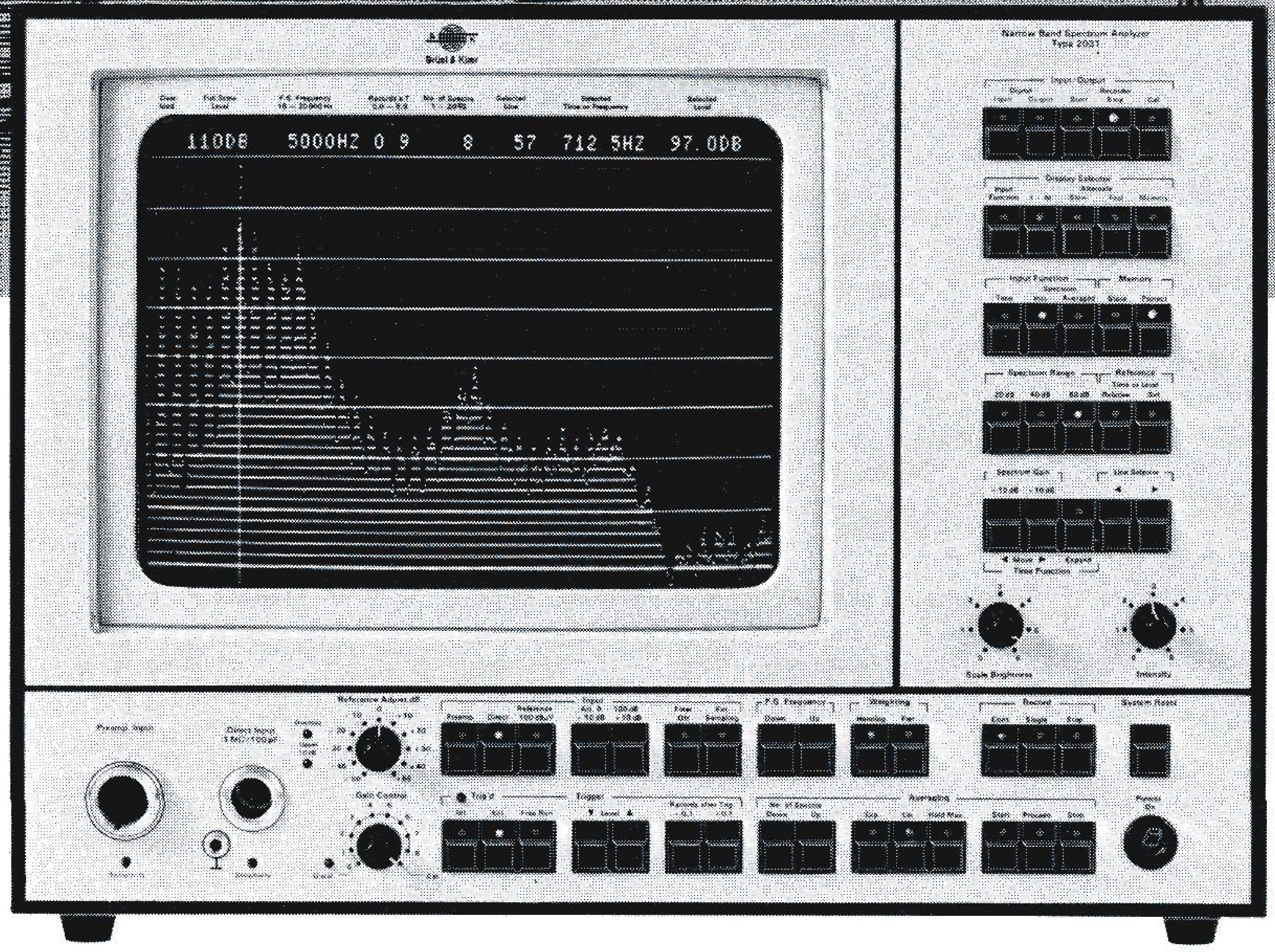
B&K Instruments, Inc.
Bruel & Kjaer Precision Instruments

application notes

Thyristors in Railway Traction

How can their effects be measured?



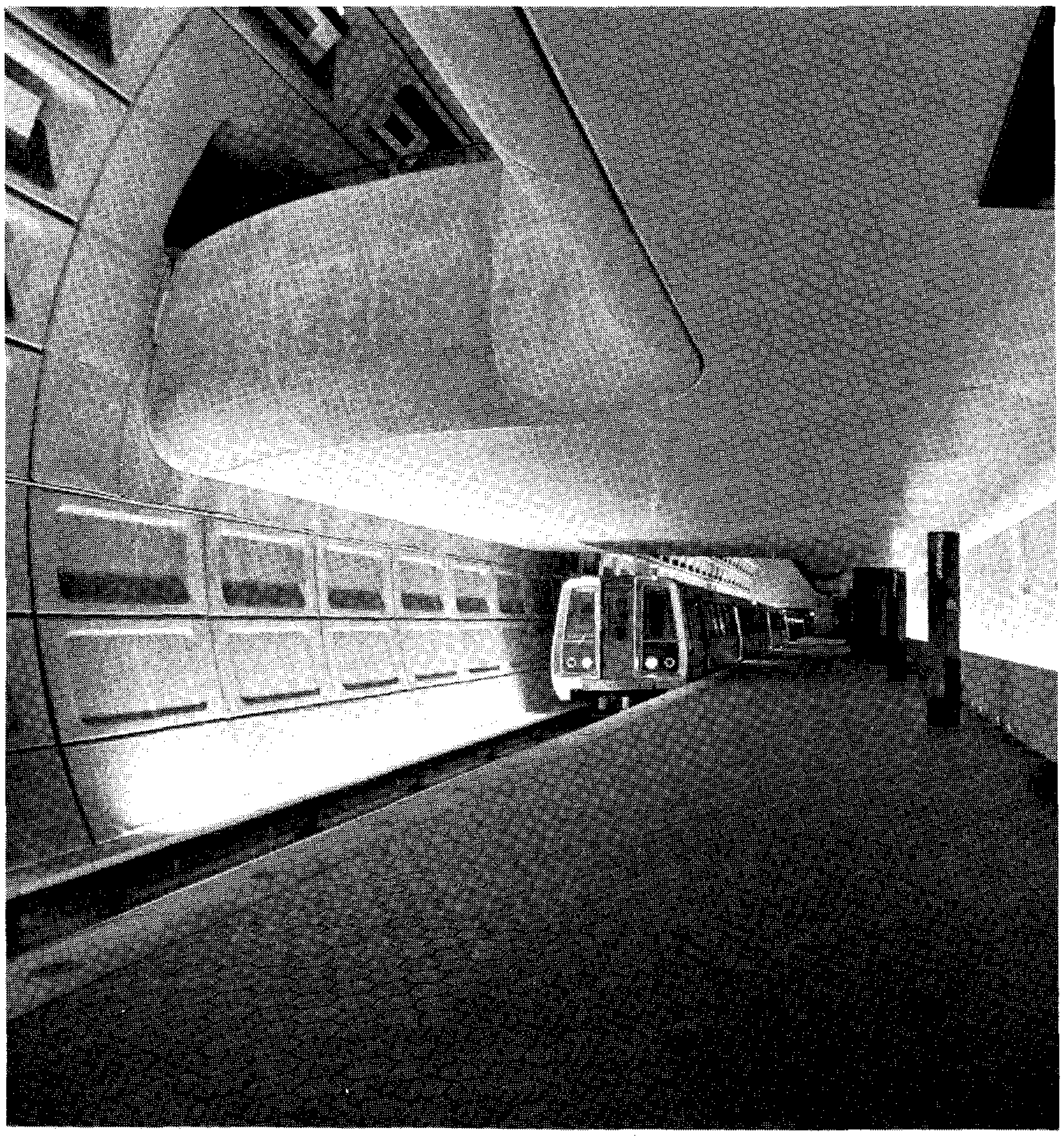


Thyristors in Railway Traction

How can their effects be measured?

by *Philip Hollingbery,* Brüel & Kjær

The use of thyristors to control the power of electric locomotives and multiple unit passenger trains (EMU's) on electrified railways is an example of a novel technology being injected into an established engineering practice. Many railway operators with busy electric lines have been attracted to the potential advantages of power electronics, only to find that thyristors create a lot of problems which cannot be measured, analysed or solved by conventional methods. The most notorious of these problems is the interference inflicted by thyristor-controlled trains on signalling and telecommunications circuits, vital for the safety of the railway.



Because of this safety problem, it is essential for any operator of thyristor traction to be able to measure and analyse this interference reliably and accurately. Many of the precision audio frequency instruments for measurement and analysis in the Brüel & Kjær range are ideally suited to the thorough investigation of thyristor effects in electric railways.

Introduction

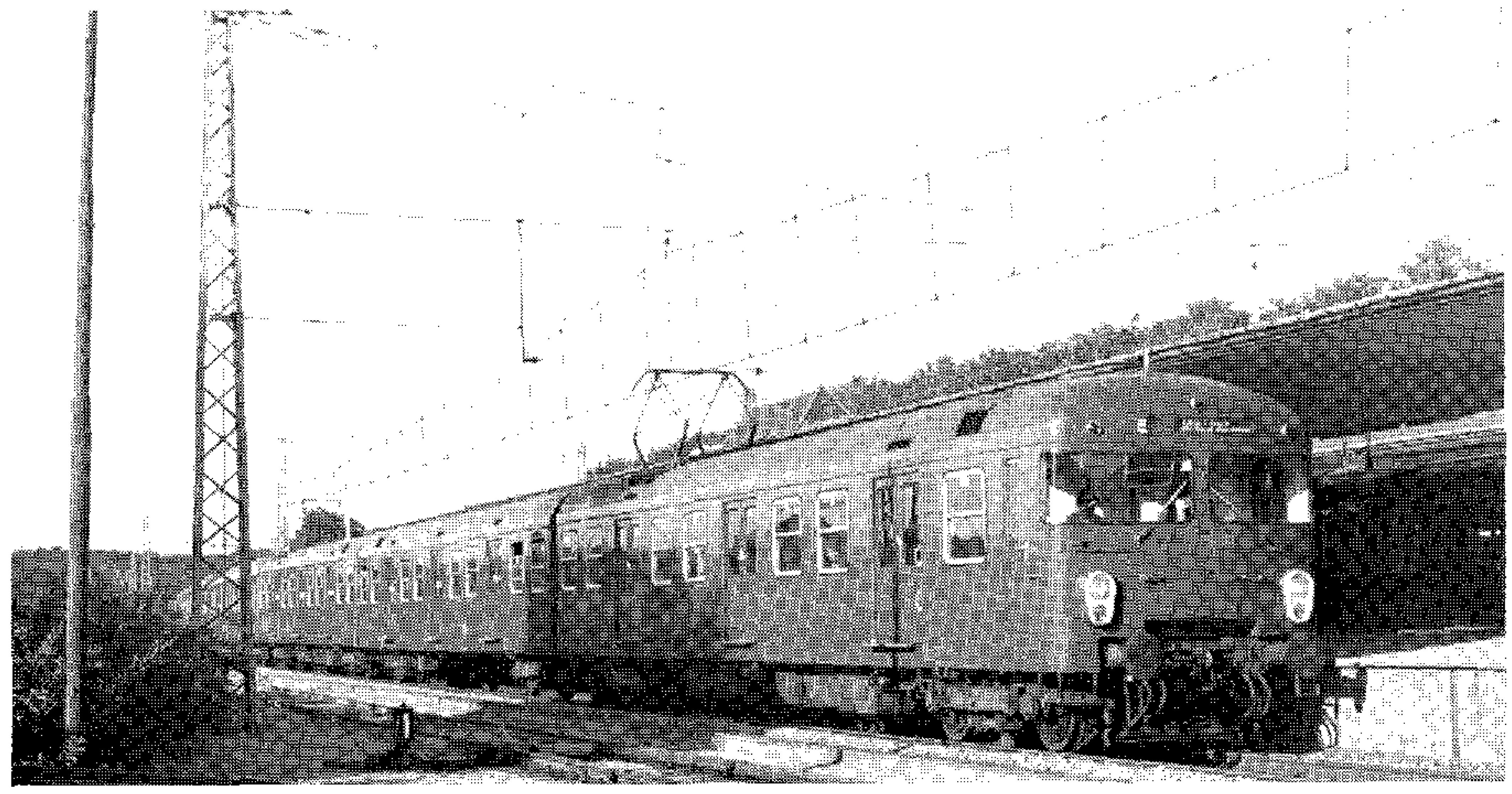
Although there are many different standard voltages and several different frequencies in use for electric railway traction supplies, all such systems belong to one of two broad groups — AC or DC.

The earliest electrifications used DC because it was cheap and simple to construct electric motors which would run directly off the lineside supply. DC is still widely used for suburban and commuter railways.

For railway electrification over long distances, AC is preferred for the same reason as it is preferred for the public electricity supply — it may be transmitted at a high voltage (and low current) — and transformed at the point of use to a low voltage (and high current).

It is a feature of electric motors used for railway propulsion that the voltage applied to the machine must be controlled over quite a wide range — typically 30:1 — to accommodate the slowly changing speed of the train, and this is where thyristors are attractive.

Established practice on DC systems is to insert variable resistances in the motor circuits, and regroup motors in series and parallel to achieve this control. On AC systems, motor voltage may be varied by selecting taps on the transformer. Both these techniques require heavy-current switching-contacts which must be very heavy and robust to avoid frequent failure and maintenance. Series resistance



absorbs significant amounts of energy and generates a good deal of heat, especially on commuter trains subjected to frequent stopping and starting.

Thyristors offer the promise of reduced weight, reduced maintenance and reduced cost — especially on AC systems. Additionally, there is considerable scope for reducing the energy consumption of trains, both by eliminating the resistances and by permitting kinetic energy from a train slowing down to be channelled back to the lineside electricity supply for use by the other trains (regenerative braking).

These benefits, which as we shall see have to be paid for, arise by virtue of the property of the thyristor of being able to switch very large currents very rapidly with no moving parts. Both on AC and DC systems it controls the traction motor voltage by acting as a variable mark-space-ratio device, switching on and off many times per second. It is much easier to switch on than off, and so thyristors are somewhat easier to use in AC traction systems, where the alternations of the supply ensure that it switches off.

Alongside the track are laid cables carrying telephone circuits, signalling circuits and train control circuits. It is a feature of electrified railways that there is a need to lay light-current cables for long distances beside electric power cables, and immunisation against induced currents and voltage in the light-current cable is established practice. However, thyristor traction usually comes as replacement equipment to an existing railway, with all the light-current circuits immunised only for conventional traction units, for which the problems are much less severe.

It is therefore very important at an early stage to measure and analyse the audio frequency currents injected by a thyristor traction equipment into its supply. To a limited extent this may be done on the test-bed. However, the real test comes when the equipment gets on to a train and out on the track, because a traction supply, with all its resonances and frequency-dependant characteristics, can influence considerably the distribution of harmonics. The ultimate test is the level of harmonic currents induced in the light-current circuits. Neither of these phenomena can be realistically examined on the test bed alone. At the same time, track trials are difficult and costly to organise, usually calling for full occupation of a busy railway, so it is essential that all the right information is obtained first time round. The methods described in the following indicate how this may be achieved.

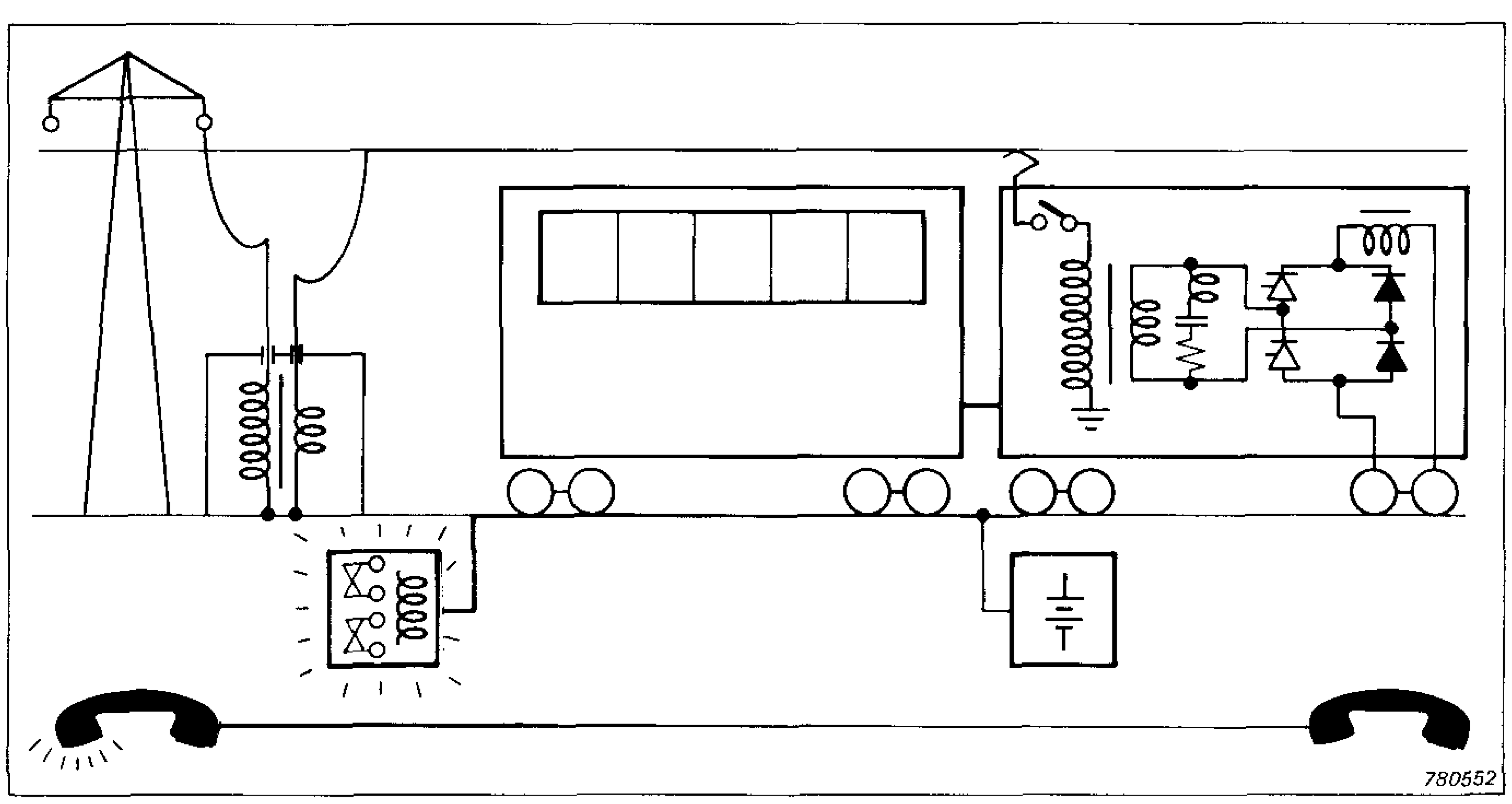


Illustration of the effects of a train with AC thyristor traction control equipment on track circuits and telecomms circuits

Tape Record the Tests

The end product of a thyristor traction trial is to test the performance of the locomotive or train and determine its effect on the telecomms and signalling circuits. This is achieved by a process of **data reduction** performed on a whole host of measurements. In other words, many measurements must be taken, much data collected, and a relatively simple result obtained — in extreme, perhaps either "Yes, the locomotive may run" or "No, the locomotive is not good enough to run".

A trials train — especially the cramped quarters on a locomotive — is not the best place to perform this process of data reduction. Furthermore, the process itself may be influenced by the results obtained. In other words, when one knows more about the system, one may want to concentrate on measuring different aspects of it.

For this reason it is most important to make instrumentation tape-recordings of **all the information** likely to be needed, and perform most of the analysis in the more congenial conditions of the laboratory afterwards. That way, you can ensure that a costly trial conducted in the middle of the night, miles from anywhere, isn't wasted.

On board the train, the most important quantities to record are the traction current and traction voltage waveforms. It helps, too, to record the train speed, either by means of a pick-off from the driver's speedometer if this is available, or by monitoring traction motor voltage. However, it is not essential to record speed automatically because the tape-recording should carry a voice track on which all important information about each part of the trial is recorded, including the speed from moment to moment. The tape-recorder releases the trials engineer from the pencil-and-paper routine, so he has plenty of time to voice all his thoughts.

Before commencing the trial, the engineer should tape-record an introduction on the voice track listing all the information about the test. The temptation should be resisted to conserve tape by reducing the speed to 1,5 i.p.s. for this part of the recording. The information to be given in the introduction might run as follows:

1. Identity of the commentator
2. Today's date
3. Tape speed
4. "Tape counter set to zero — Now!"
5. The location
6. The vehicle being tested
7. The identity of the signal recorded on each tape track
8. The sensitivity settings of each channel in terms of 40% FM carrier deviation (e.g., pantograph-current = 300 amps, train speed = 200 km/hr etc.)
9. Details of tests, e.g.:
   running-line and direction
   make-up of test train
   traction motor current
   any special modifications to the vehicle

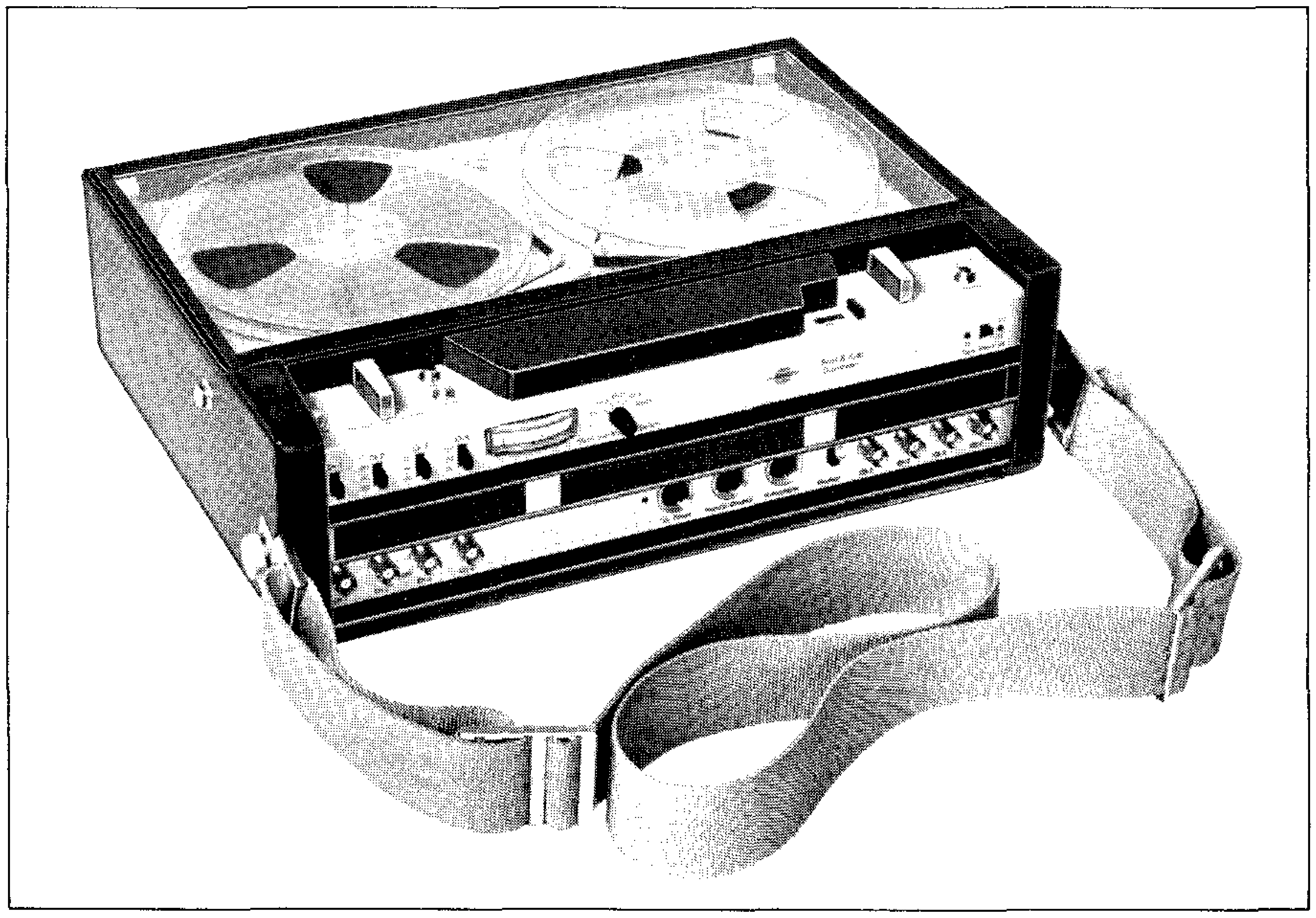
Remember also to calibrate each FM channel of the tape recorder beforehand, because there are always going to be requirements to know the absolute levels of the currents and voltages subsequently.

At the lineside it is necessary to make recordings of telephone circuit noise, substation current and voltage, and (on DC electrified lines) induced signals in track circuits.

In most cases low-level monitoring devices, such as current transformers, will be installed to enable a tape-recorder to be connected safely to the traction circuits.

The Brüel & Kjær Type 7003 tape-recorder fulfills all the requirements for this application. Here are its features:

* 4-channel FM recordings to IRIG Wideband Group 1 Standard on quarter-inch tape, so you can reserve your 7003 for trials use and replay the recordings on bigger, heavier machines kept permanently in the laboratory
* Flat response from DC to 10 kHz with no phase shift at low frequencies, for correct reproduction of waveforms as well as signal levels
* The first instrumentation FM tape recorder to be designed specifically for use in the field, only 7,6 kg (16,8 lb) weight and 100 × 270 × 380 mm (4 × 11 × 15 in) in size
* 24 minutes of continuous recording at 15 inches per second, with the facility for 4 hours continuous recording at 1,5 i.p.s. and reduced bandwidth
* Versatile power requirements — choice of internal rechargeable supply, external 12 V vehicle battery supply or mains 50—400 Hz 100—240 V
* Better than 1% DC drift
* Standard BNC signal connections



The B & K Type 7003 4-channel FM Instrumentation Tape Recorder

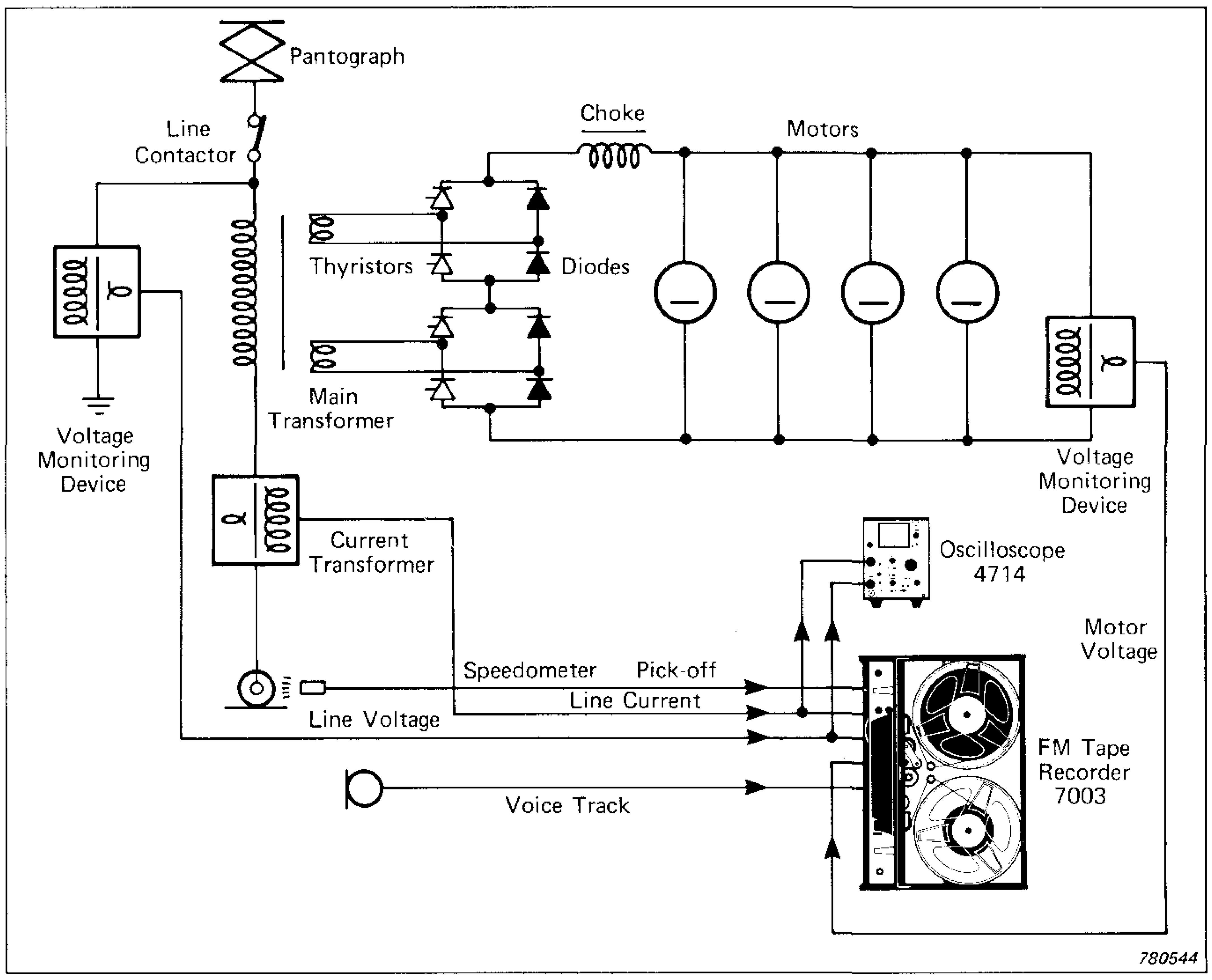
Monitor what is going on

You may not want to do much analysis of signals during a trial, but it is important to know you are recording the right signal, and not mains hum or something totally unexpected. A two-channel oscilloscope in the cab of the train, at the substation or the telephone junction box will tell you a lot of things quickly and keep you informed about the test. For example, on an AC system the traction voltage waveform tends to be sinusoidal close to the substation, but at other locations the presence of a load (not necessarily the trials train) will cause the line to "ring" electrically at quite high harmonics of the supply, and with a little experience it is possible to determine which are the dominant harmonics. The ideal traction current waveform is square, but in practice its shape quickly reveals the speed of the train and its approximate power factor, as well as the level of harmonics.

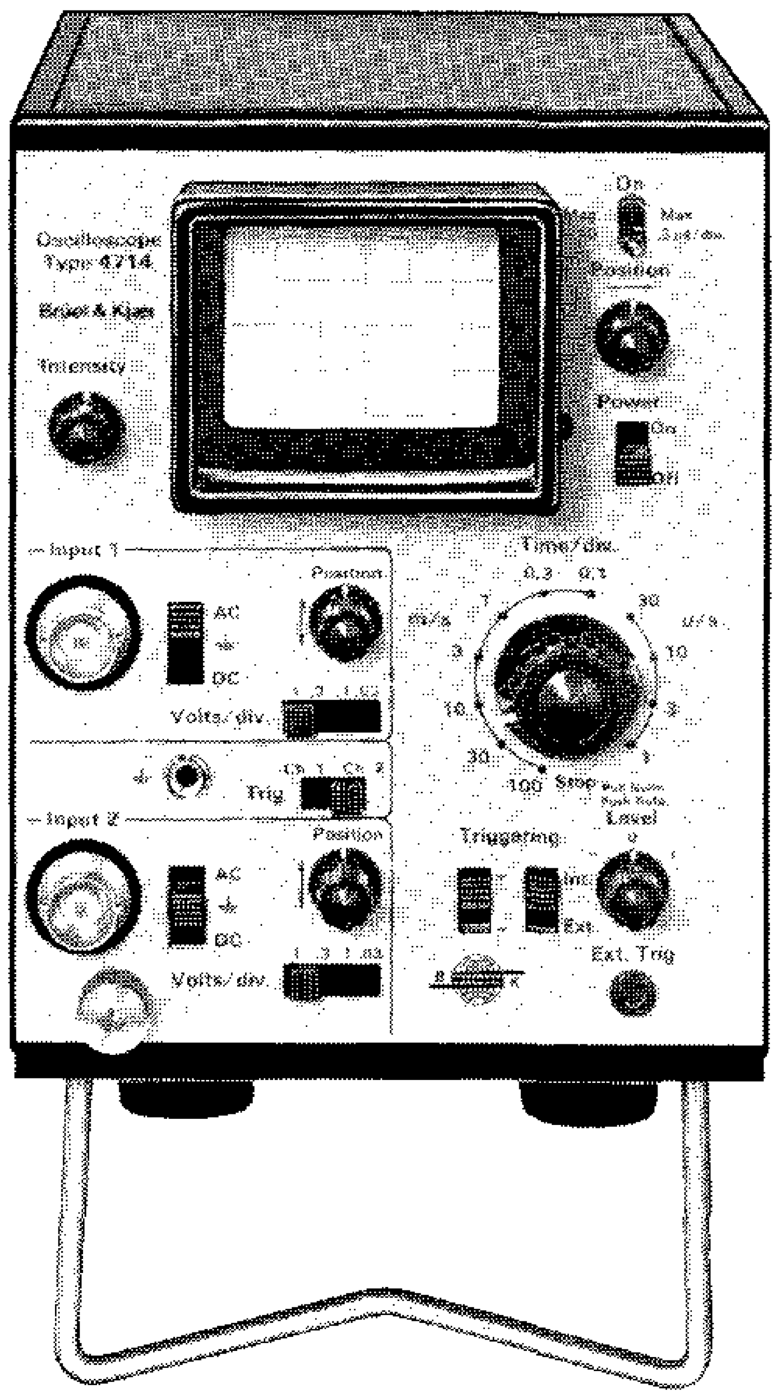
As with the tape-recorder, the requirement is for maximum portability and, preferably, independence of a mains supply. There is no requirement for extra features like delayed sweep or high sensitivity, but it is important to get a good linear display and negligible phase shift at low frequencies.

The Brüel & Kjær Type 4714 is one of the smallest measurement oscilloscopes available, because it has been designed to fit into the B & K Module System alongside other compact, portable instruments. It has the following features:

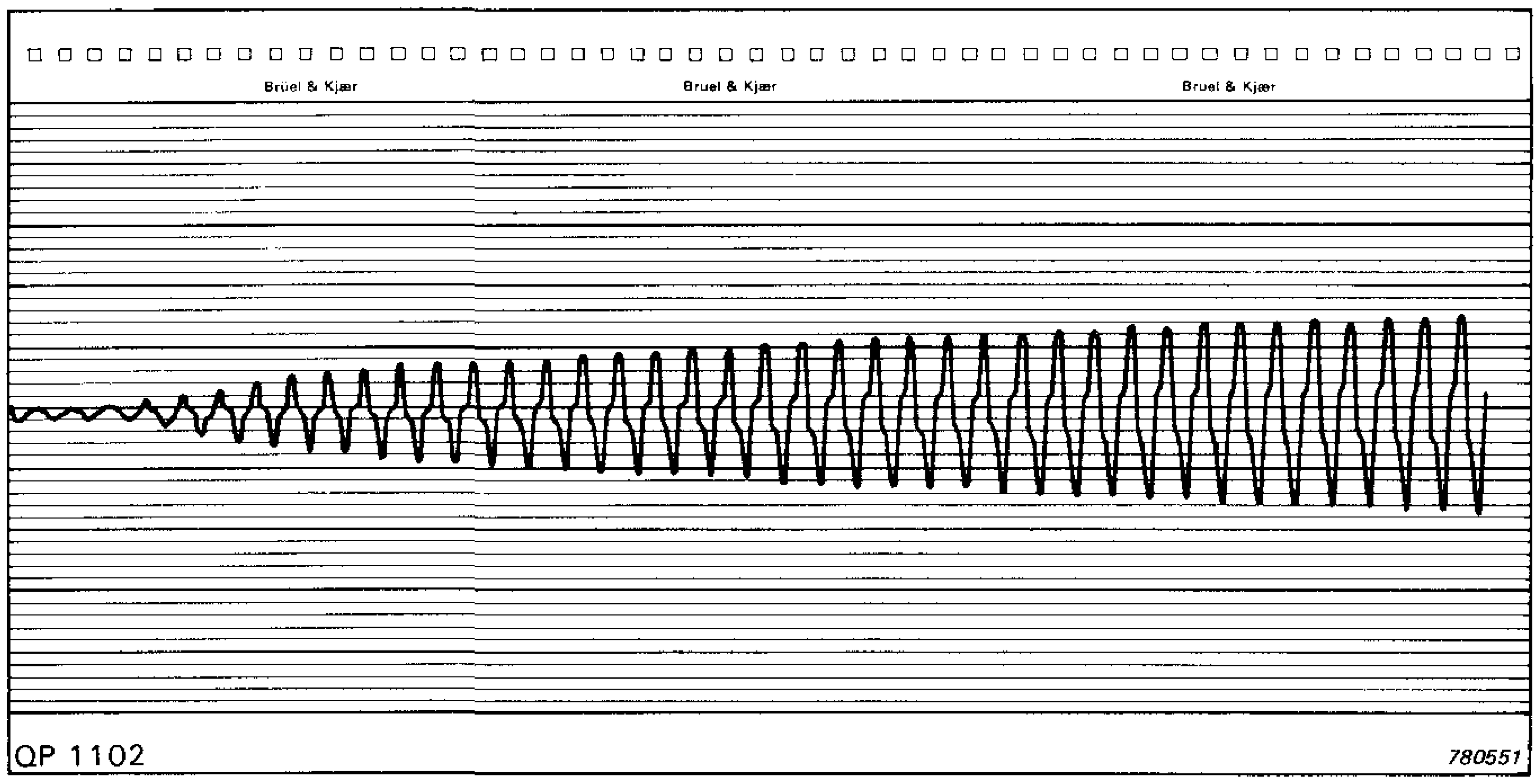
* 2,0 to 2,2 kg (4,4 to 4,85 lb — depending on power source) weight, 133 × 105 × 200 mm (5,23 × 4,12 × 7,88 in) size — easily lost in a locomotive driving-cab!
* Can be powered either from internal 6,3 V rechargeable battery pack giving 5 hours' operation per charge, or an internal mains adaptor for 100 — 230 V 50 — 60 Hz mains operation (a compartment in the body of the 'scope will accommodate either of these items, which may be quickly changed over in the field)
* DC to 5 MHz bandwidth, ± 5% calibrated gains on both channels of 0,03; 0,1; 0,3; 1 V per division
* Calibrated time-base 1 μs to 100 ms per division with full triggering facilities
* Standard BNC signal connections



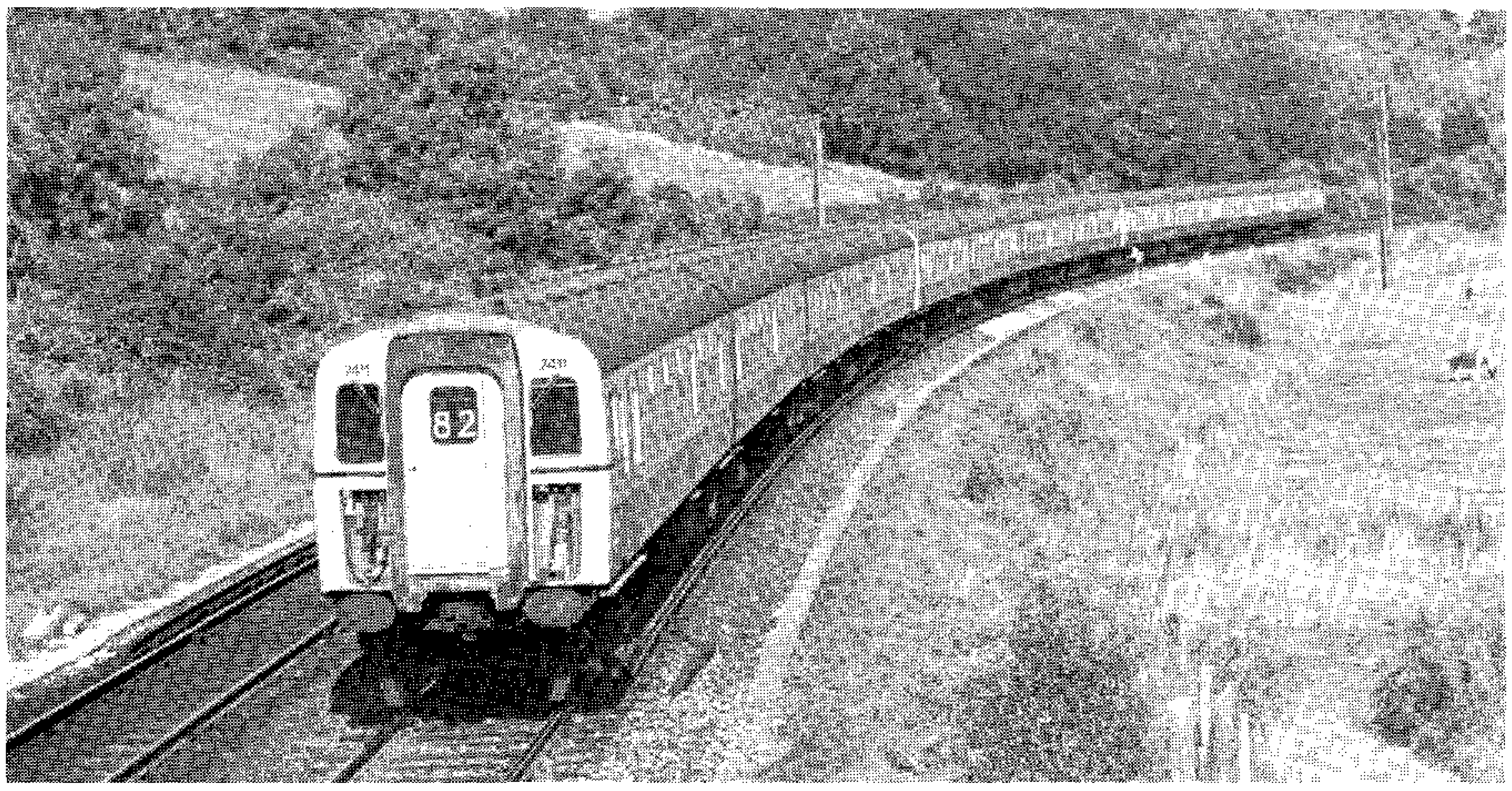
Typical connection diagram for oscilloscope and tape recorder on board a trials locomotive

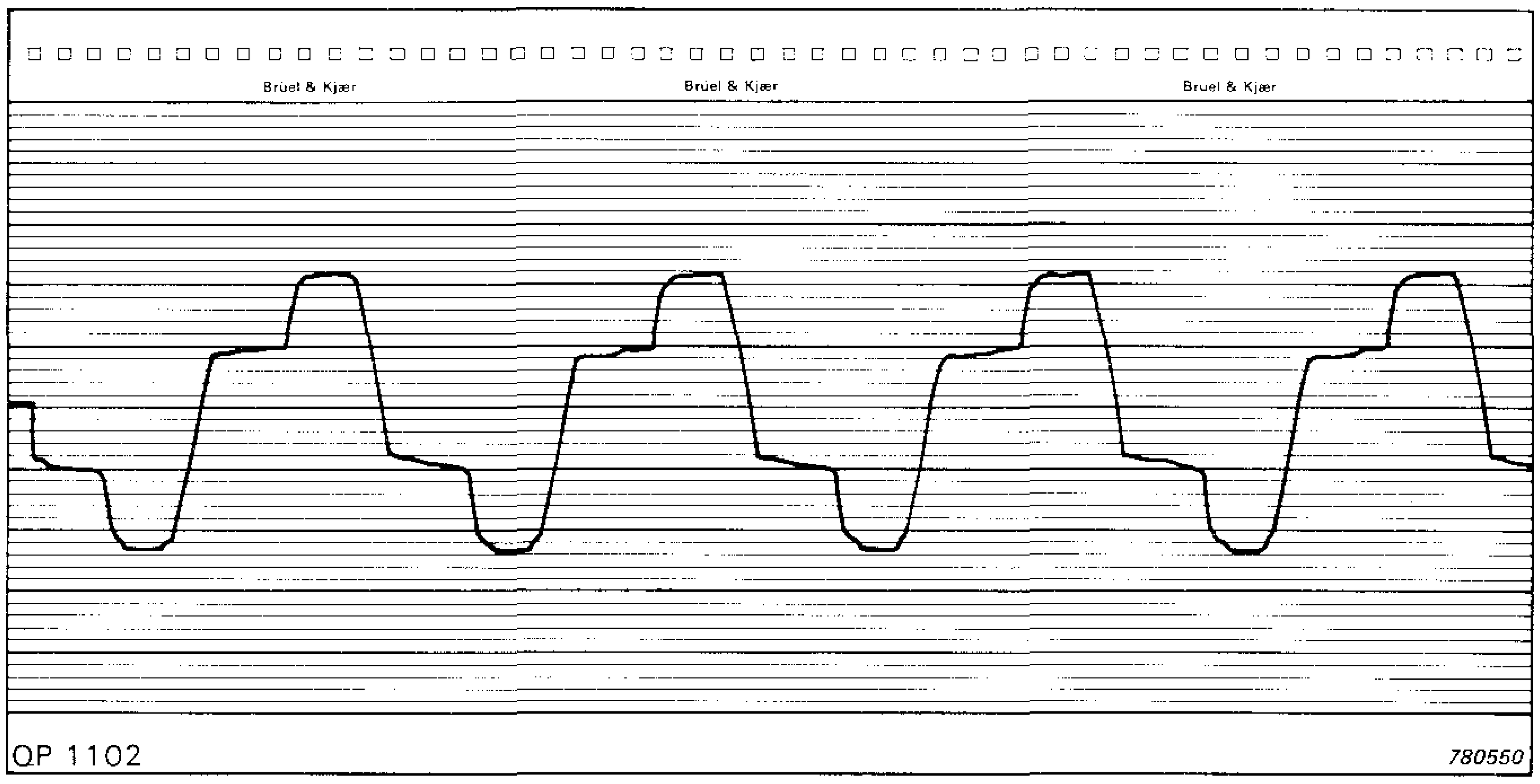


The B & K Type 4714 Portable 2-Channel Oscilloscope

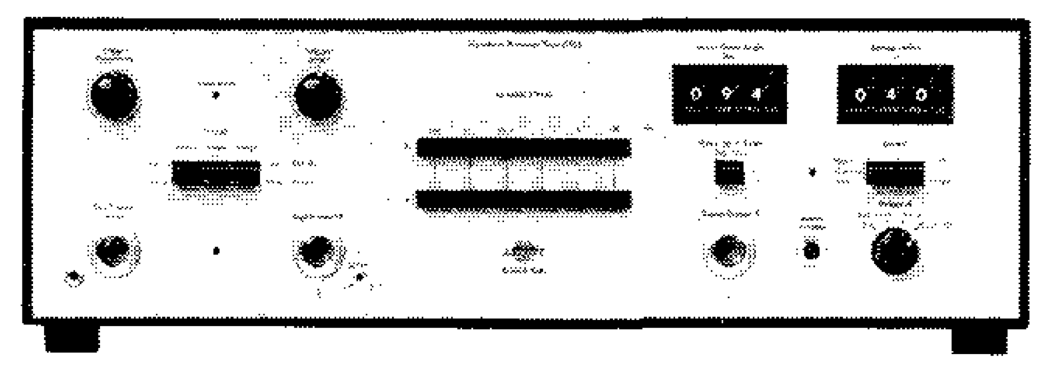


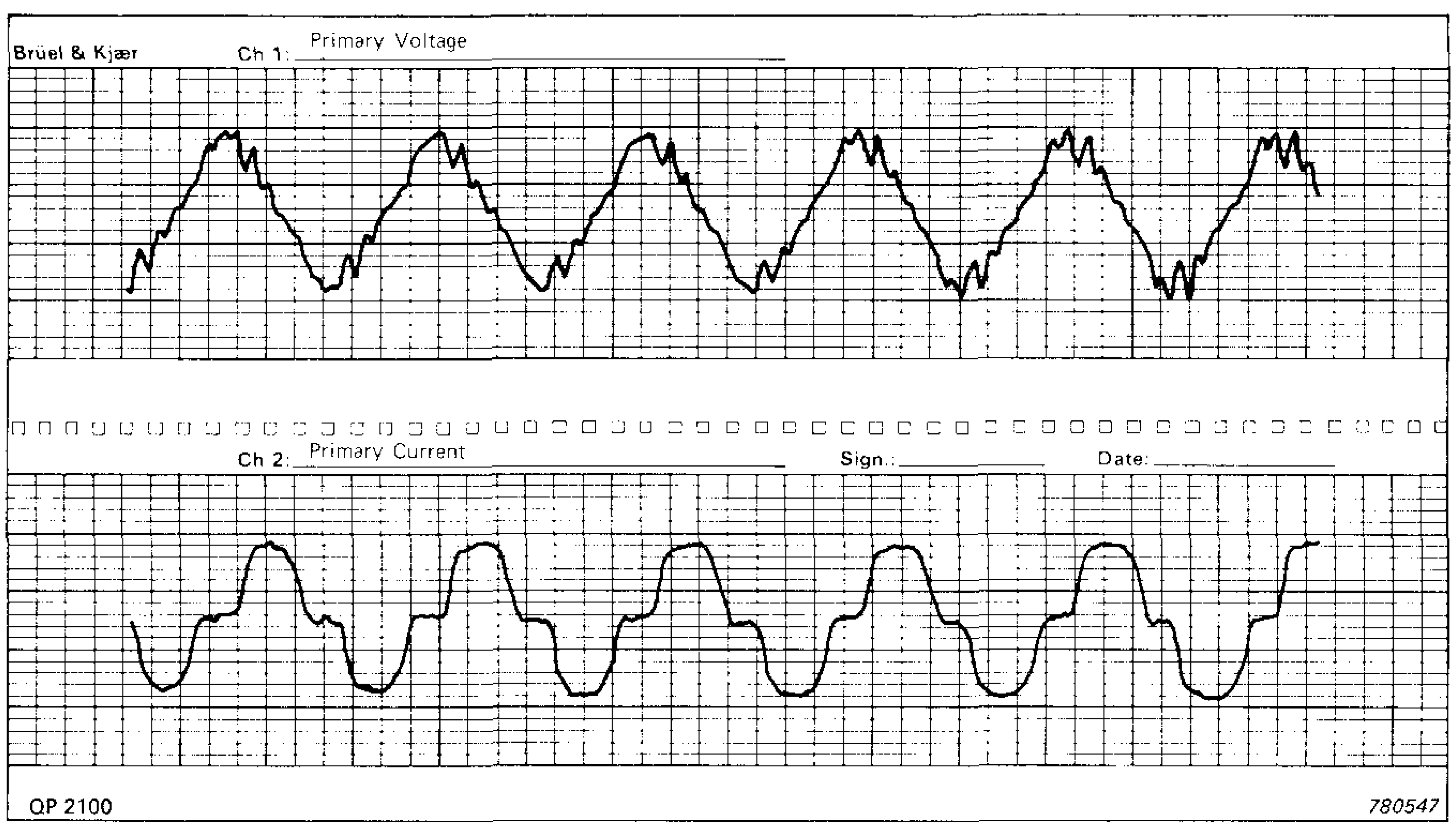
Waveform recording of the build-up of pantograph current in a 50 Hz thyristor locomotive during the first 680 ms of the application of power. Note the highly distorted waveform. 1 division = 24 A. The recording was made using a Type 7502 Digital Event Recorder and a Type 2307 Level Recorder





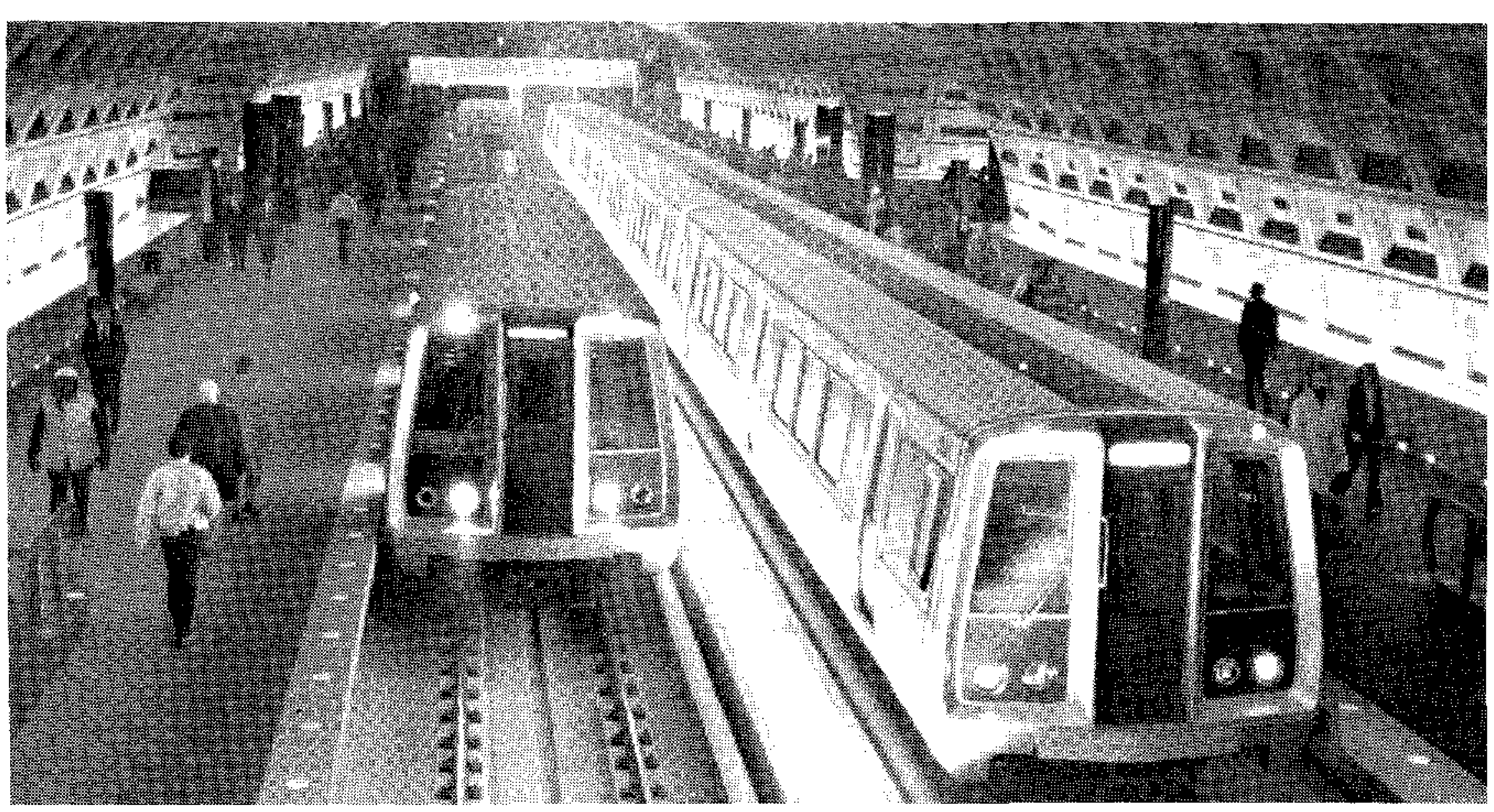
Waveform recording of 25 kV 50 Hz thyristor locomotive primary current at approximately 90° advance on second rectifier bridge (1 div. = 24 Amps). Second bridge is indicated by the fact that the two 'steps' in the cycle are staggered by about 220 Amps. It can be deduced that the armature current is approximately 110 Amps, multiplied by the transformer turns ratio (referred to one secondary), divided by the number of armatures in parallel. Quite a lot can therefore be determined even from one waveform





Waveform recording (left) of thyristor locomotive primary voltage (upper trace) and current (lower trace), made with B & K Type 6302 portable two-channel Waveform Retriever (above) and Type 2309 Portable Two-Channel Level Recorder (p.16). The Waveform Retriever is an instrument for enabling accurate chart recordings to be made of repetitive waveforms with frequency components up to 10 kHz, even when the wanted signal is buried in noise. In this recording 1 division = 7,5 kV and 24 Amps vertically and 2,8 ms horizontally.

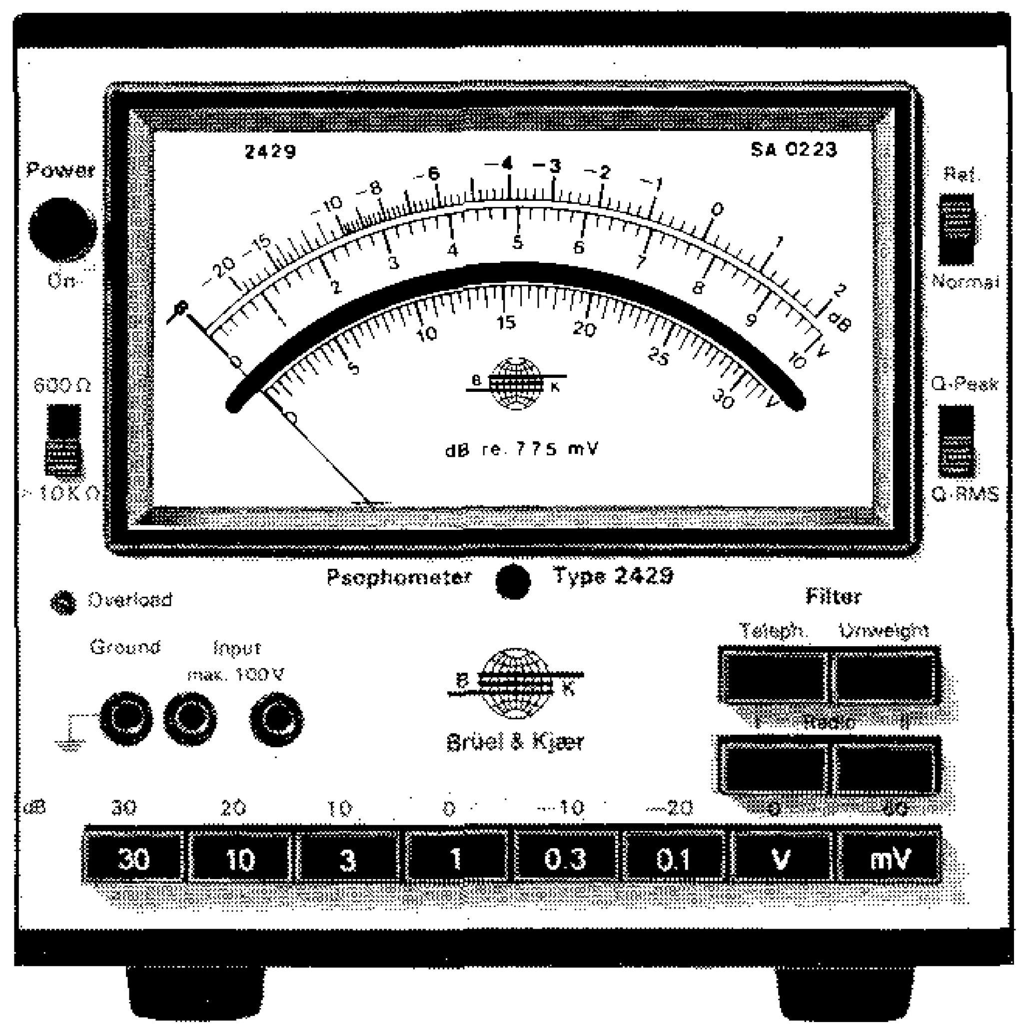
The current waveform shows that the locomotive has about 80° of advance on one rectifier bridge. This can be deduced from the fact that the current lingers at zero amps for two significant parts of the cycle. Furthermore the marked ringing on the voltage waveform occurs just after each voltage peak. Note that commutation from thyristors to diodes (at the trailing edge of each current peak) causes almost no perturbation on the voltage waveform. The waveforms are recorded in their correct time-relationship with this arrangement of instruments, and the lagging power factor is easily observed



Psophometric noise in telephone circuits

On AC systems the harmonics produced by thyristor control equipments tend to lie at lower audio frequencies than on DC systems, mainly within the restricted bandwidth used for telephone circuits. Furthermore, the lengths of these circuits are longer on inter-city routes (which are usually AC electrified) than on commuter routes, (which are generally DC electrified), increasing the coupling between cables. Telephone interference is therefore more of a problem when thyristors are introduced on AC systems, than on DC systems. It is also worse generally on the newer industrial-frequency electrifications (50 and 60 Hz) than the older "railway" frequency systems (16-2/3 and 25 Hz) because the predominant harmonics from the latter lie at lower frequencies, outside the telephone bandwidth (usually 200 Hz to 3 kHz) and there is less excitation of transmission line resonances. Because the quality of telephone speech is not usually higher than it needs to be for intelligibility, for reasons of economics, some interference from electric traction units is generally tolerated, and the level of immunisation on telephone circuits is chosen to provide the best compromise between cost and intelligibility. However, when a new electric traction unit is introduced to an existing system and generates a different pattern of interference, its effect on intelligibility must be measured.

Intelligibility is a subjective matter. Different frequencies interfere more or less with speech, and the annoyance level of a given frequency is also dependant on the bandwidth of the wanted speech signal. Consequently, to measure noise objectively in a telephone circuit one needs both a measuring amplifier and a weighting filter to weight the different frequencies according to the results of statistical experiments on human subjects. The weighting filter used for this purpose is known as a psophometric filter, and the complete instrument is a psophometer. It is also common to refer to the noise measured with it as psophometric noise.

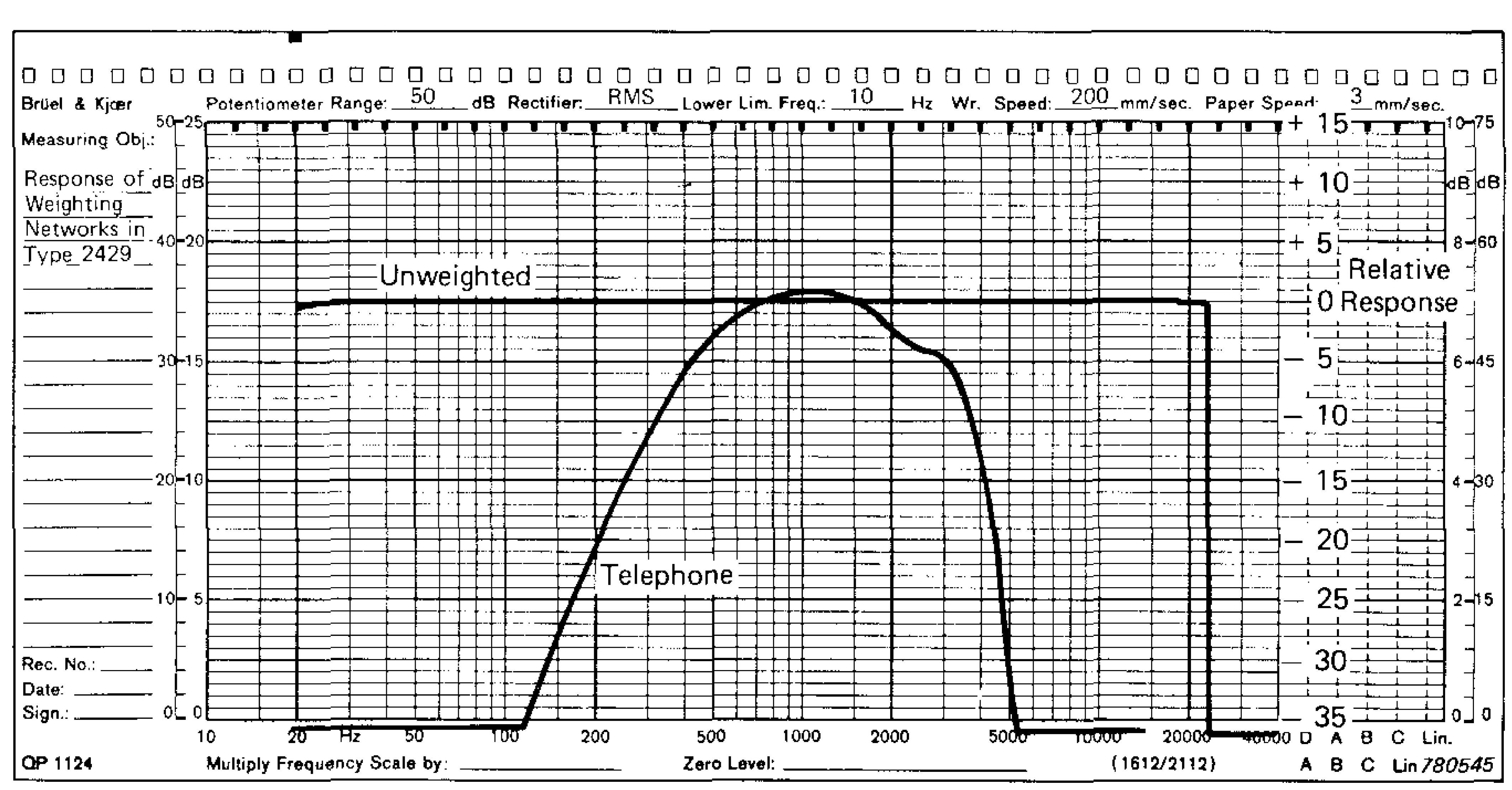


Type 2429 Psophometer

The Brüel & Kjær Type 2429 psophometer conforms to the requirements of CCITT P53 and DIN 45405 for telephone circuit noise measurement. It may be used at the site of the trials, powered from a pair of external batteries (18 to 25 V), or in the laboratory (to measure the signal recorded on tape), powered from 50 to 400 Hz, 100 to 250 V mains. Connection to a telephone circuit is made using a 3-pin plug to DIN 41 628 (B & K part no. JP 0316). The input includes a transformer providing symmetry and a high level of isolation from potentially hazardous voltages which may be induced in the telephone circuit from the traction supply.

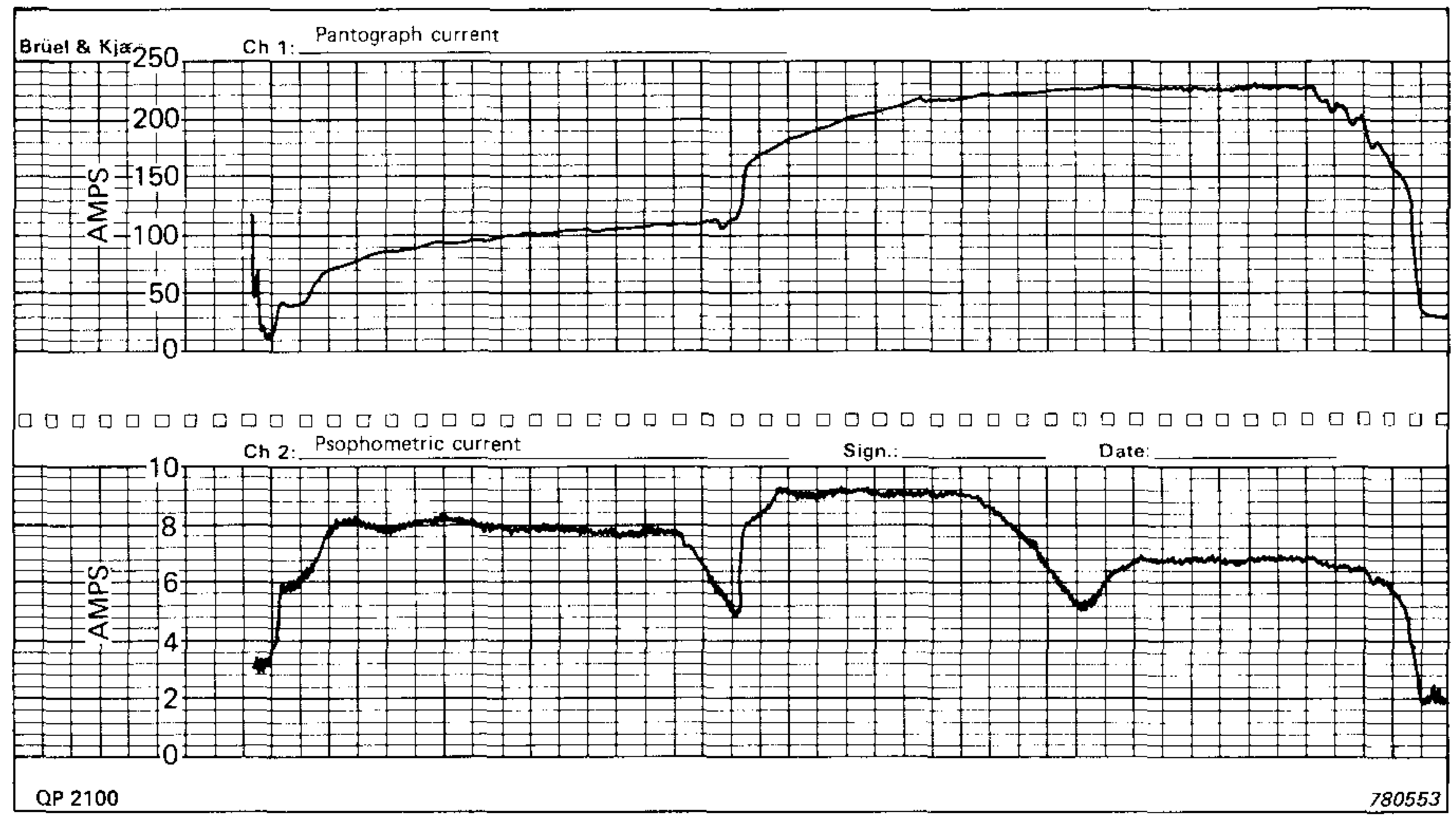
The psophometer has 12 voltage ranges (at 10 dB intervals, i.e., × 3,16 increments of sensitivity) from 100 μV to 30 V RMS full scale deflection, and a built-in calibration source which may be used without disturbing the range setting, and which also permits subsequent instrumentation (such as a level recorder) to be calibrated at the same time.

A versatile selection of outputs is available for recording and monitoring purposes. There is an AC output (on a BNC socket) providing 3,16 V RMS out from a low impedance at full scale deflection, with a peak capability of 14 V. There is a DC output (also on a BNC socket) with less than 50 Ω source impedance, + 3,16 V DC at full scale deflection and a peak capability of + 14 V. Linearity of this signal against input RMS level is better than ± 2,3% of level between 25% and 78% of meter full scale deflection, and better than ± 6% of level between 8% and 245% of meter full scale deflection. There is a headphone outlet on a pair of screw terminals capable of accepting bare wires or banana plugs. Finally there is a 7-pin DIN socket carrying both AC and DC outputs, battery inputs, and a line for an external capacitor which may be connected to increase the averaging time of the RMS detector.

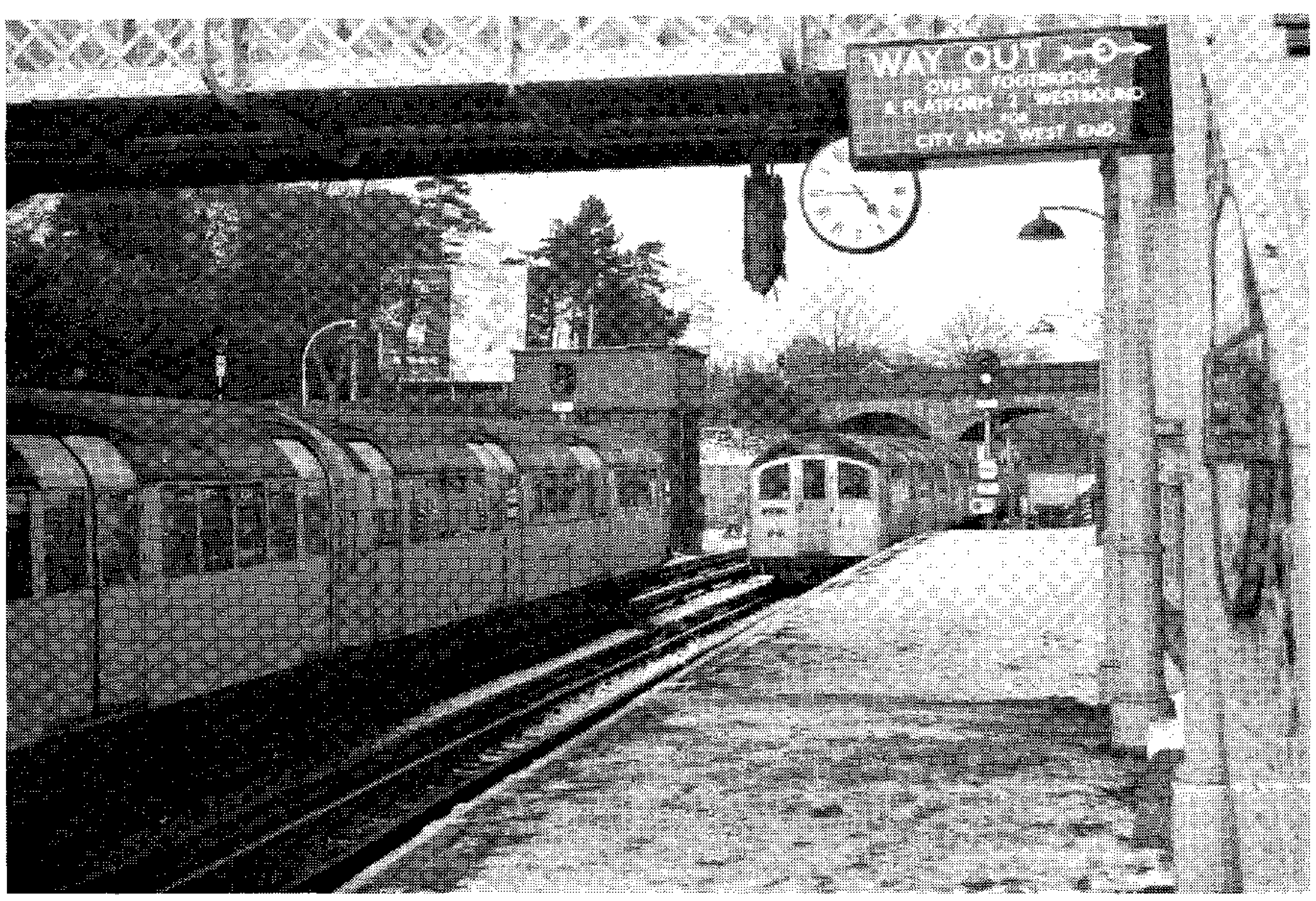


Response curves for Telephone Weighting and Unweighted characteristics of the Type 2429 Psophometer. Note that both the amplitude and frequency axes of this graph are logarithmic, in contrast to the spectra on pages 7 to 14. A logarithmic frequency scale is useful for frequency analysis of transmission paths (of which the ear and an electrical network are two examples), although over a range of less than two decades of frequency, either linear or logarithmic scales may be used

This external capacitor facility is useful for eliminating low-frequency fluctuations of signal level, which can occur for example when the psophometer is used to measure the level of noise on a tape-recording from a telephone circuit, and the output of the psophometer is plotted on a level recorder. It is often difficult to eliminate mains hum at a low level completely from the circuit (even though the Type 2429 has a balanced input which facilitates the elimination of earth loops), and if the tape recording is made on a railway electrified at industrial frequency, slight variations in this frequency and tape shrinkage can result in beats which, though not large enough to cause errors, produce a wiggly line on the level recording and cast suspicion on all the measurements!



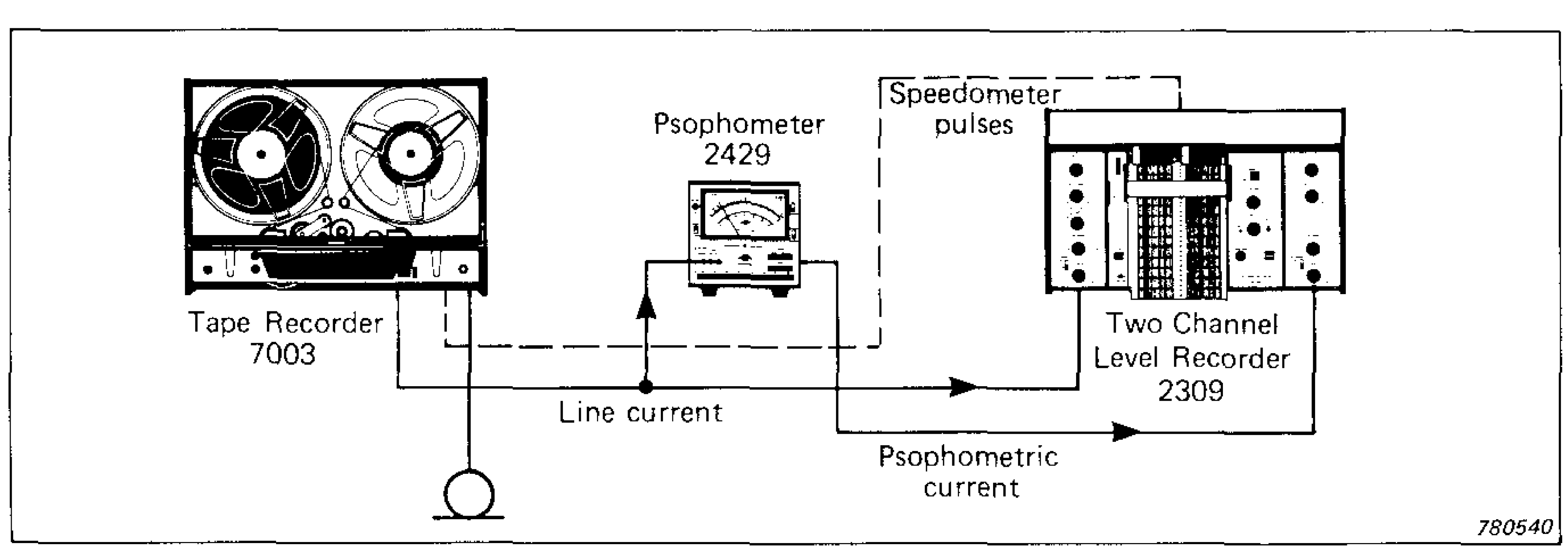
Log of pantograph current (= primary current) and psophometric current as functions of time, during an acceleration at constant armature current. The time scale is 5 s/div. For the first 80 s only one bridge is conducting



The traction current may be several hundred amps, and the psophometric component will range from a few amps to perhaps 20 A in the worst cases. It is best measured on the train, at various positions on the railway (e.g., close to substation, remote from substation, etc.), but useful information can also be obtained by measuring it while the equipment is still on the manufacturer's test-bed and connected to the factory supply. The psophometer has an isolated input (500 V), but it should certainly not be connected directly to a 25 000 V supply, and in any case it is necessary to convert from amps to volts to make the measurements. Therefore a good-quality current transformer, or a shunt and an isolating voltage-transformer, must be provided with the necessary degree of isolation. It is best to use a DC voltage transformer with a good frequency response.

The Type 2429 psophometer weighs only 3,4 kg (7,5 lb) and is designed to fit into the B & K Module System, so it is quite portable enough for field use.

Although the coupling between the traction supply and an adjacent telephone circuit is notoriously difficult to predict, and may include a differential characteristic, it is quite possible to measure it on an existing system, and so predict the level of induced psophometric noise from new electric traction unit by measuring the psophometric current injected into the supply by the new equipment.



Arrangement of equipment for logging Line Current and Psophometric Current as functions of distance travelled

Frequency analysis of thyristor traction

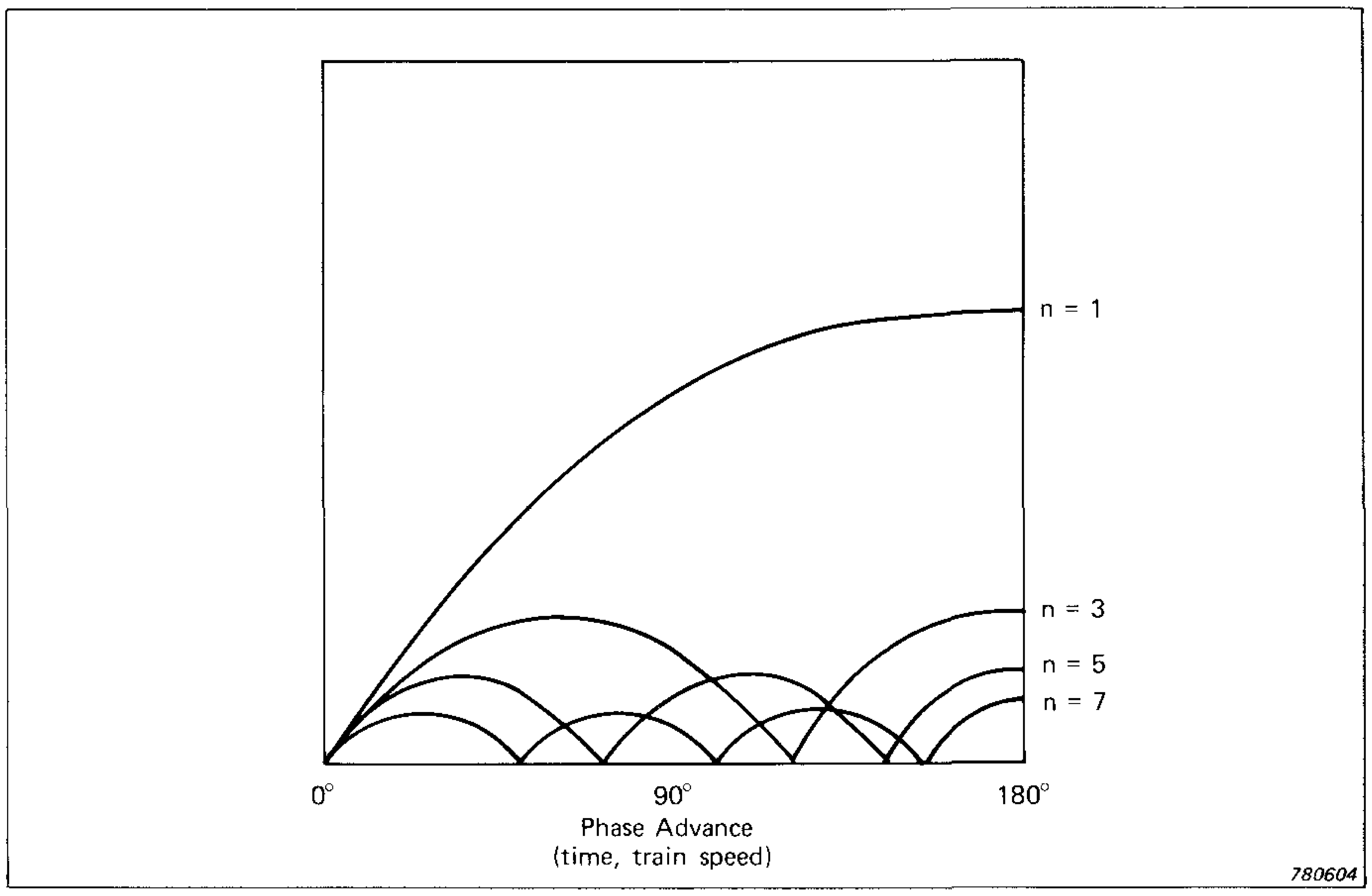
One of the most important data reduction processes which an engineer engaged in commissioning or evaluating new thyristor controlled rolling-stock is called upon to undertake is the analysis of the frequency content of the traction current or the induced voltages in light-current circuits. The audio-frequencies which are likely to be encountered in the traction supply are as follows.

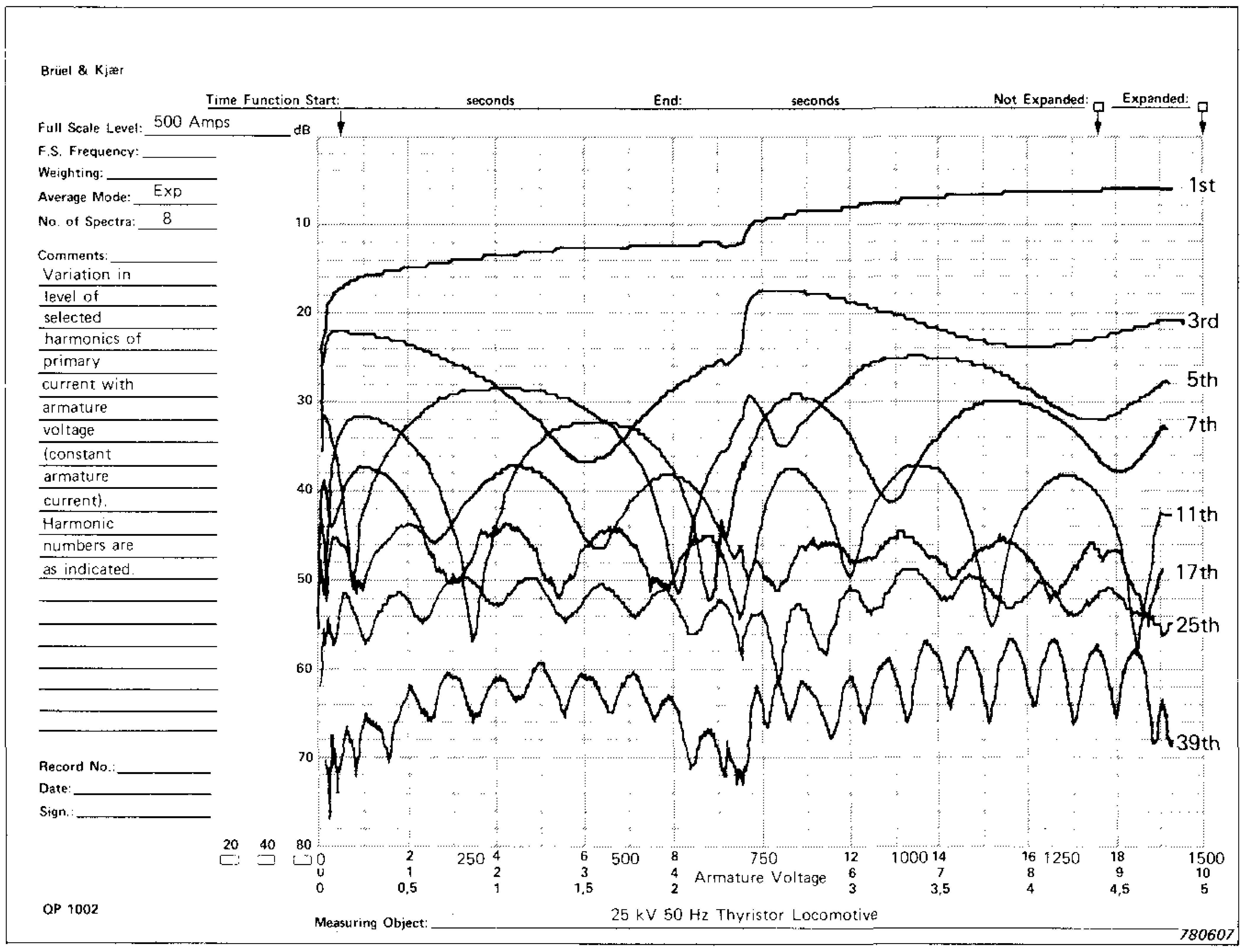
On AC electrified railways:

1. the supply frequency and its exact harmonics, predominantly odd harmonics
2. slow transients containing a wide range of frequencies and some even harmonics of the supply, caused by traction transformer inrush or wheelslip correction

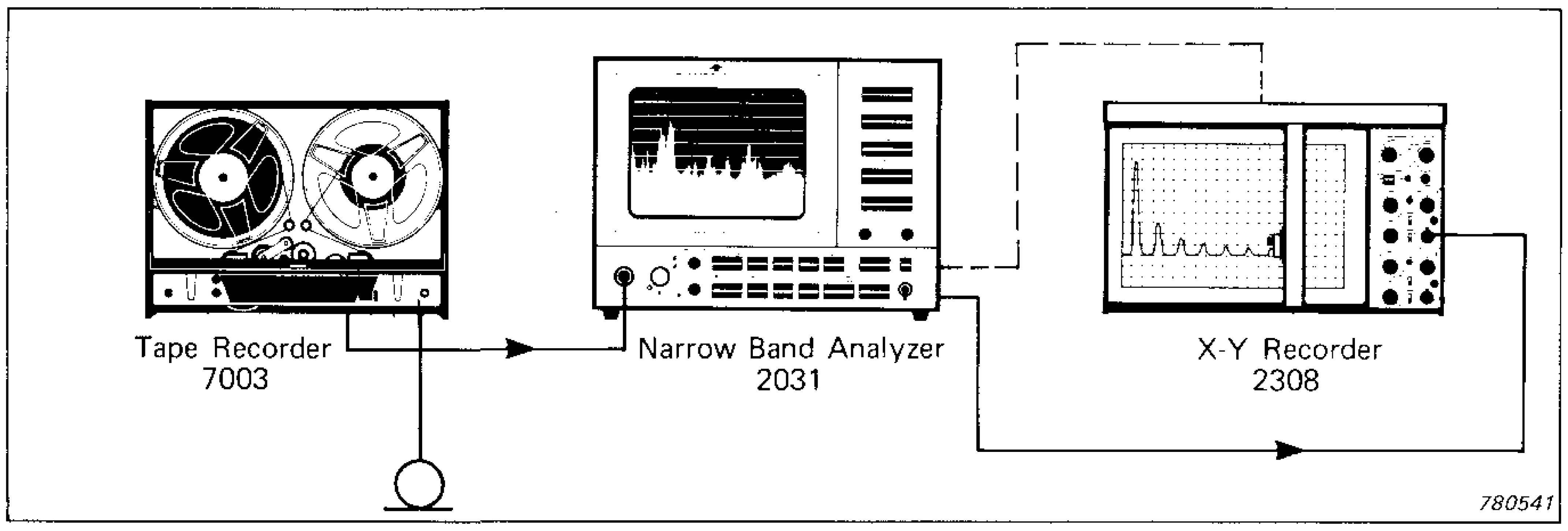
On DC electrified railways:

1. the chopping frequency, usually a few hundred Hz, and its exact harmonics, predominantly odd
2. the industrial frequency (50 to 60 Hz) and its harmonics, mainly the 3rd, 6th and 12th, resulting from the substation rectifier used to provide the DC traction supply
3. slow transients containing a spread of frequencies caused by line filter inrush at the closing of the circuit breakers on the train, or wheelslip correction





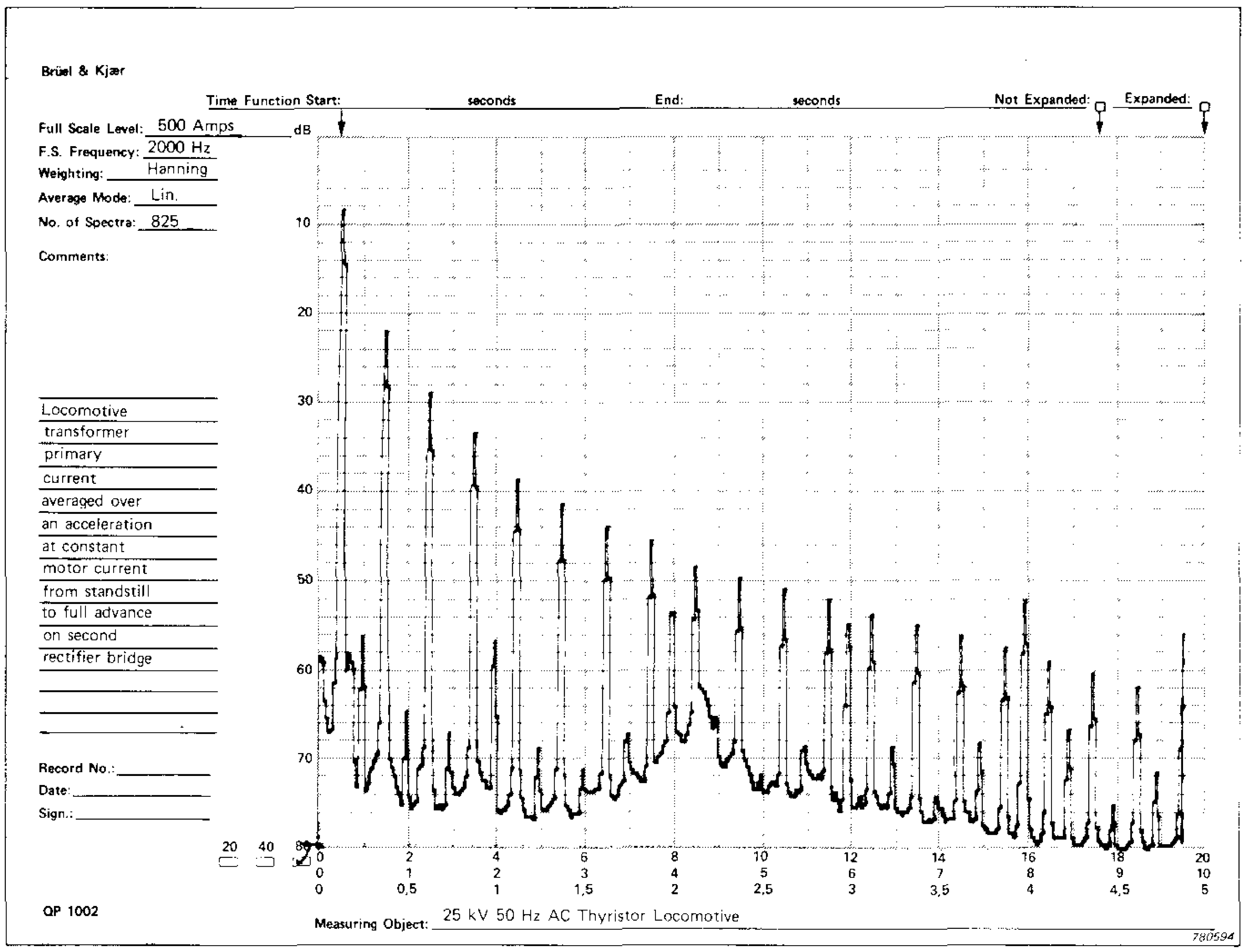
As an AC thyristor locomotive accelerates, the level of each harmonic fluctuates cyclically. The upper figure shows idealized plots, on a linear amplitude scale, of the levels of the first four odd harmonics as functions of phase advance, for a single rectifier bridge (n = harmonic number). The lower figure shows the actual behaviour of eight selected harmonics, recorded as functions of armature voltage, on a logarithmic (dB) amplitude scale, for a two-bridge system, using a B & K Type 2031 Narrow Band Analyzer and a Type 2308 X—Y Recorder

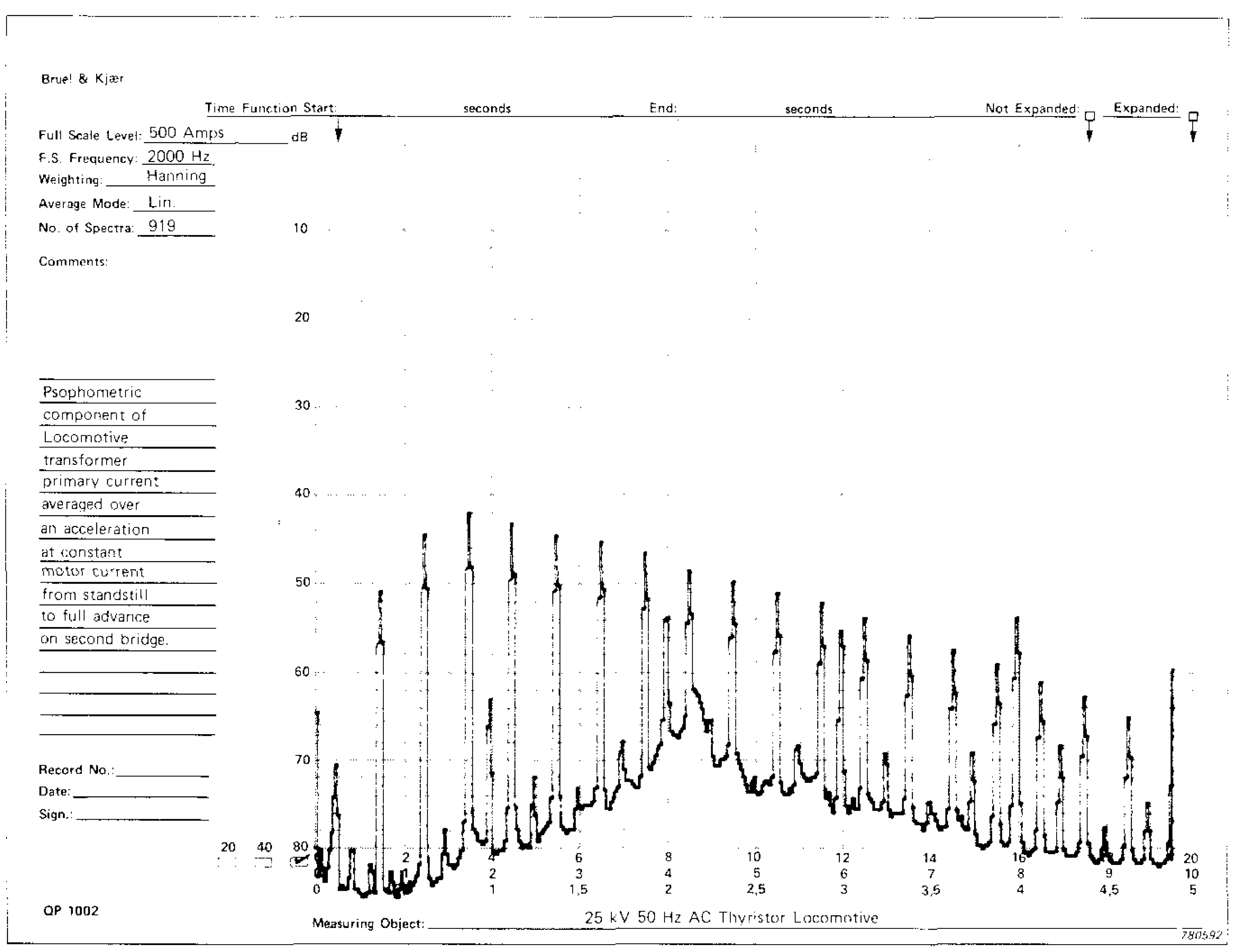


Arrangement of equipment for plotting spectra of Line Current

On both kinds of electrification systems, some operators have vehicles propelled by commutatorless motors fed with continuously variable frequencies, usually obtained from the traction supply by thyristor inverters. These equipments can inject currents into the supply at harmonics of the inverter frequency, usually the 6th and its multiples.

On AC electrified railways the main problem is the psophometric noise discussed above. Track circuits used for signalling are designed to operate either from DC, or at a frequency not harmonically related to the supply, so they are almost totally immune to supply-related interference. The relays used for track-circuit indication are designed to have a very narrow-band characteristic which rejects interfering currents very effectively. However, there can be a risk of a false indication arising from the passage on an inverter vehicle if it should happen to be travelling at just the right speed for long enough to activate the relay.





These two figures show spectra of primary current with psophometric weighting (lower trace) and unweighted (upper trace). Note that the strongest harmonic in the psophometric current is the 7th (350 Hz). These plots are actually averages of nearly 1000 spectra made at 200-ms intervals throughout the same acceleration at constant armature current. Like most of the figures in this section, these spectra were recorded using a Type 2031 Narrow Band Analyzer and a Type 2308 X—Y Recorder; they illustrate the useful ability of the 2031 to display the average of a large number of spectra, as well as instantaneous spectra. The Type 2429 Psophometer was used to perform the weighting

On DC electrified railways the same kinds of problems arise but the details are sufficiently different to merit discussion. Psophometric noise is less important because the frequencies tend to be higher and the distances shorter than on AC. The main problem is that practice on DC electrified railways is to use AC track circuits to prevent them from responding to currents leaking out of the traction supply, but they can respond falsely to AC induced by thyristor equipments because the level of traction current itself is so much higher on a DC electrification system than on an AC system. This is particularly true of inrush current, which contains a variety of frequencies.

Without going into further detail, we can see that the traction supply carries current at many frequencies which can interfere with light-current circuits, and whenever the psophometric or unweighted level appears to be excessive, it is essential to analyse those frequencies and decide what to do about the dominant ones.

There is, however, a further difficulty scarcely touched on hitherto. A power engineer measuring the currents in a traction supply would normally feel some confidence that if he added up all the currents taken by all the trains fed from one given substation, the sum would be almost equal to the total current delivered by that substation. At DC and 50/60 Hz this would be a reasonable expectation. At higher frequencies nothing could be further from the truth.

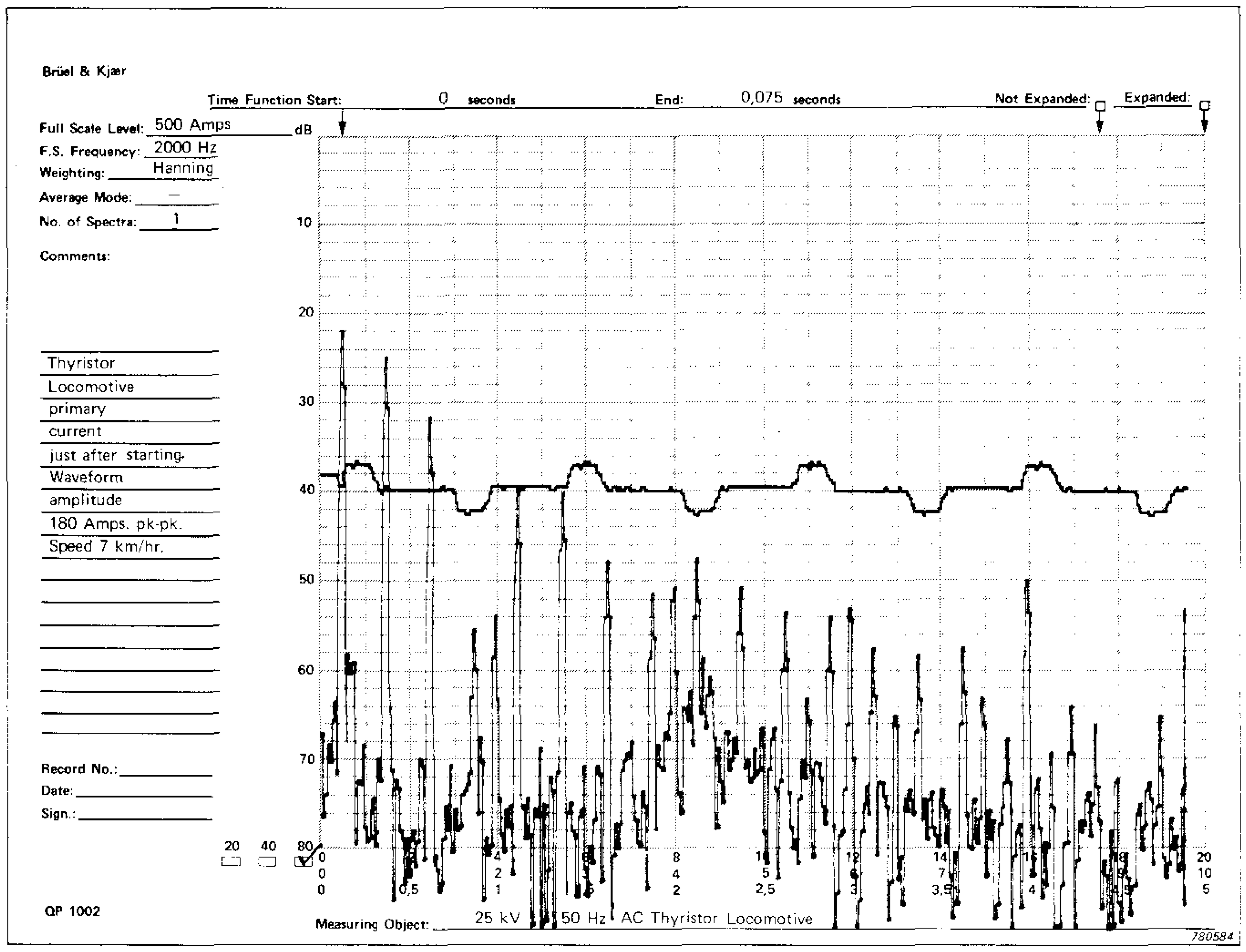
This is because at higher frequencies the supply network must be treated as a network of transmission lines, with lumped inductance and capacitance, resistance and leakance, to which the telegraphy equations must be applied. Its transmission characteristics are rather poor by telegraphy standards, and it suffers from all sorts of resonances because at some frequencies there will be line sections close to the quarter-wavelength. All these factors are complicated by aspects of construction of the catenary and influenced by components such as booster transformers.

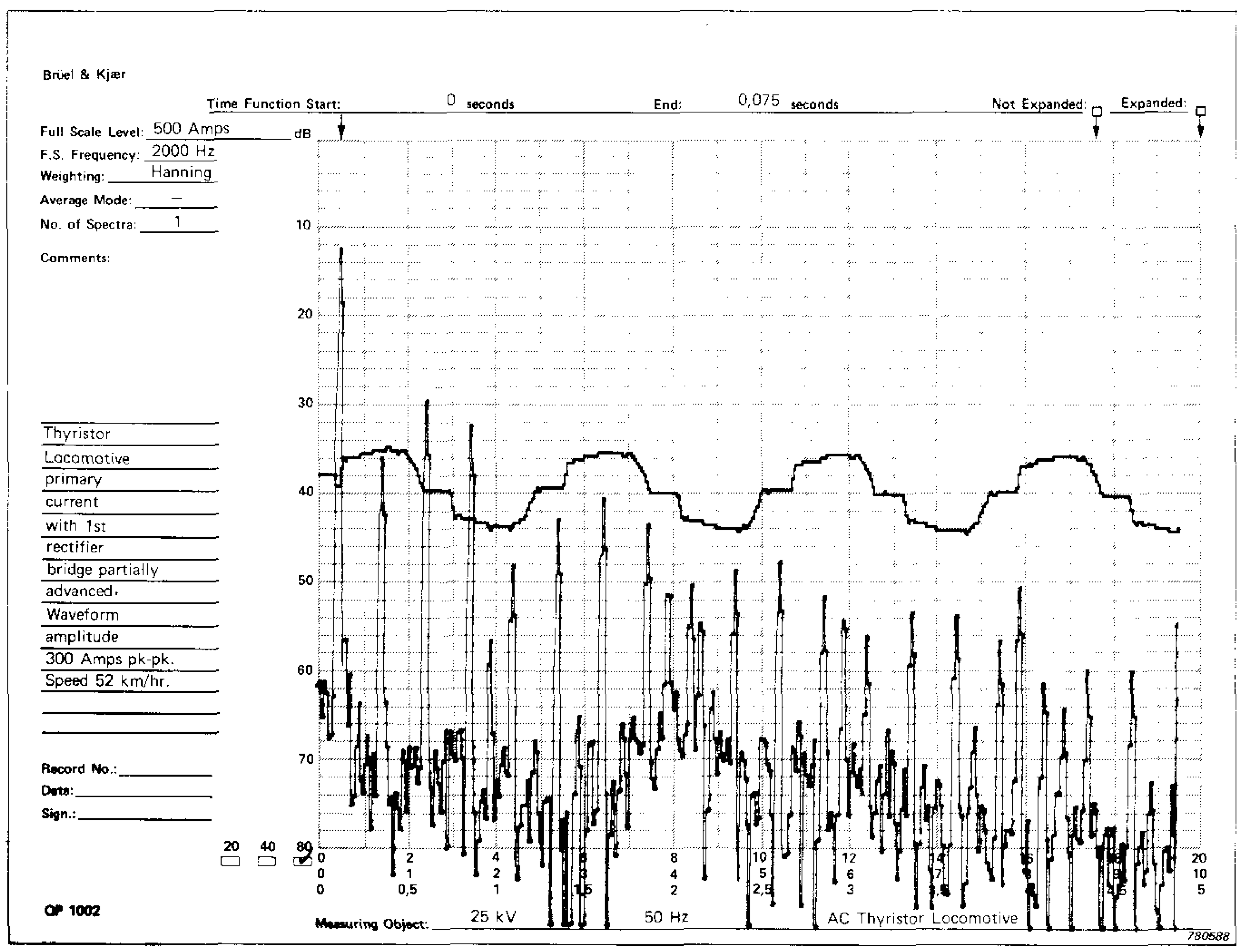
At higher frequencies the engineer who has measured zero amps at the train, and zero amps at the substation, can still not state with complete assurance that he would measure zero amps in a track circuit or a telephone circuit somewhere between the two. It is a reasonable assumption, but when lives are at stake it is a good idea to go and confirm it.

There is therefore a need for a lot of data and a lot of analysis. What is more, every railway and every stretch of railway is different, because no stretch of line is built for the S & T engineer's benefit. So a lot of experience is necessary before predictions about the effects of thyristors can be made without any measurement or analysis.

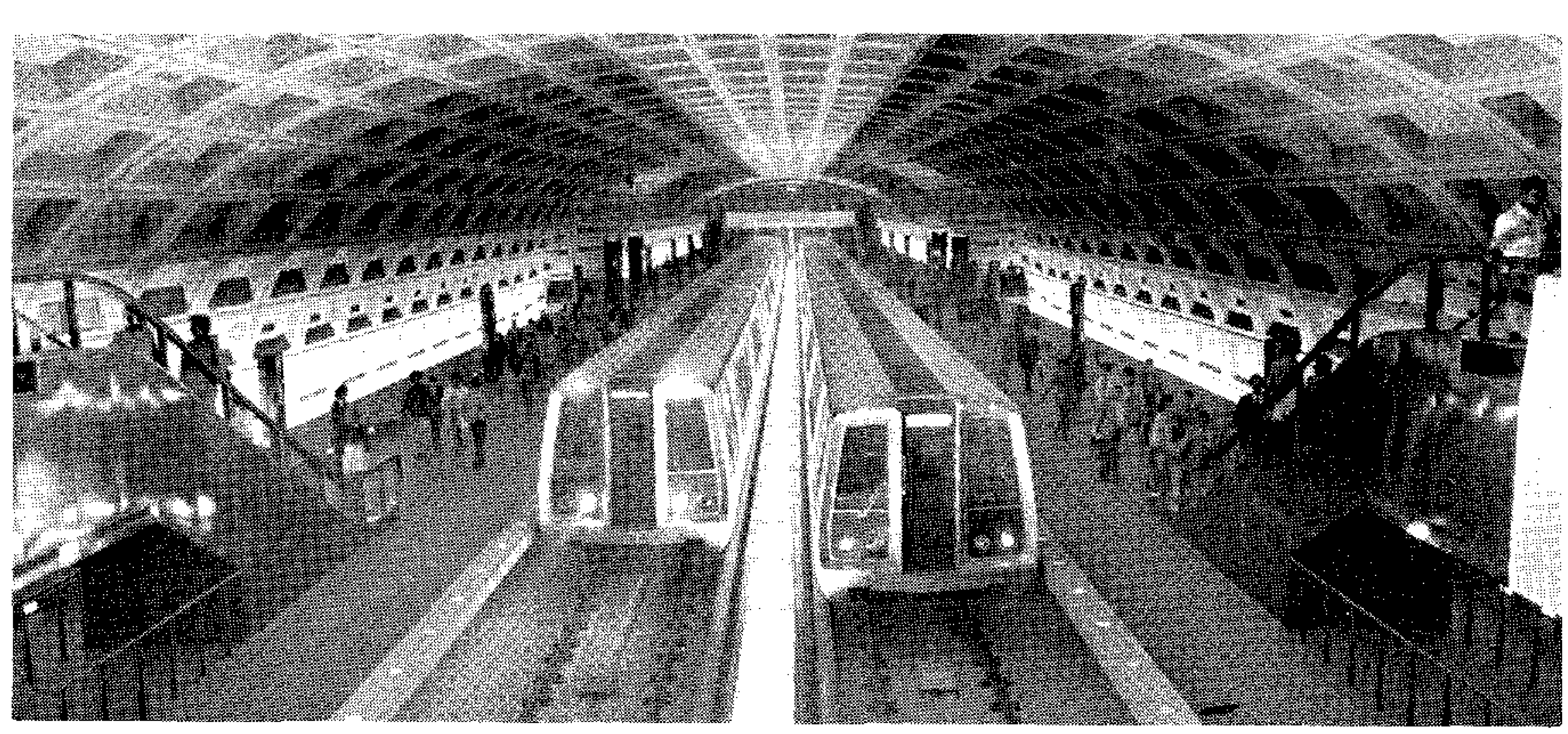
Because frequency analysis is a major part of sound and vibration work, Brüel & Kjær make a wide range of equipment for tackling different kinds of frequency analysis. Many of these could be used with advantage to find out something about the effects of thyristors on an electric railway. However, to do the job thoroughly one needs a spectrum analyser, and to do the job without occupying all the engineers available all the time, one must use a real-time narrow-band analyser, such as the B & K Type 2031 Narrow Band Spectrum Analyzer.

It is not difficult to understand why. Suppose you have a tape recording of a signal, and you have measured the psophometric content and found that for part of the time this exceeds the permissible threshold. The chances are that one or two particular harmonics are causing the trouble, so you get a suitable narrow-band filter or analyser and play the tape through it once for each harmonic, recording the output on a level recorder. You may, after five or six runs, find what you want, but equally well you may find that all the harmonics fluctuate considerably (as the train accelerates), and none of them individually would account for the psophometric level.





The figures on this page and pages 10 and 11 show the waveform and instantaneous frequency spectrum of locomotive primary current at six stages during an acceleration at constant armature current. In the stages shown on this page only one rectifier bridge is conducting. Use is made of the facility of the Type 2031 Narrow Band Analyzer to display spectra or waveforms; it is not essential to record them on the same plot, as here



The next possibility to consider would be the use of a swept-frequency analyzer. This consists of a narrow-band filter (with a 3 dB bandwidth B Hz, say), sweeping at a rate of S Hz per second through the frequency range from 0 Hz to n_{max} f Hz (where n_{max} is the order of the highest harmonic analyzed and f is the fundamental frequency). The output of the filter is detected by a rectifier, and the DC from this rectifier is smoothed by an RC filter. The output from the RC filter is logarithmically converted and fed to a graphic level recorder or cathode ray tube having a horizontal sweep facility synchronized with the sweep of the filter.

The filter bandwidth B should be narrow enough to resolve adjacent harmonics differing in amplitude by more than 10 dB. This means that B should be about one-third of the interval between peaks. If it is required to resolve only odd harmonics (which is all an ideal assymmetric half-controlled bridge rectifier generates in the supply),

$$B = \frac{2f}{3} \text{Hz}.$$

To resolve even harmonics at a low level, such as 30 dB lower than adjacent odd harmonics, the bandwidth would have to be more than proportionately narrower and the sweep rate much slower.

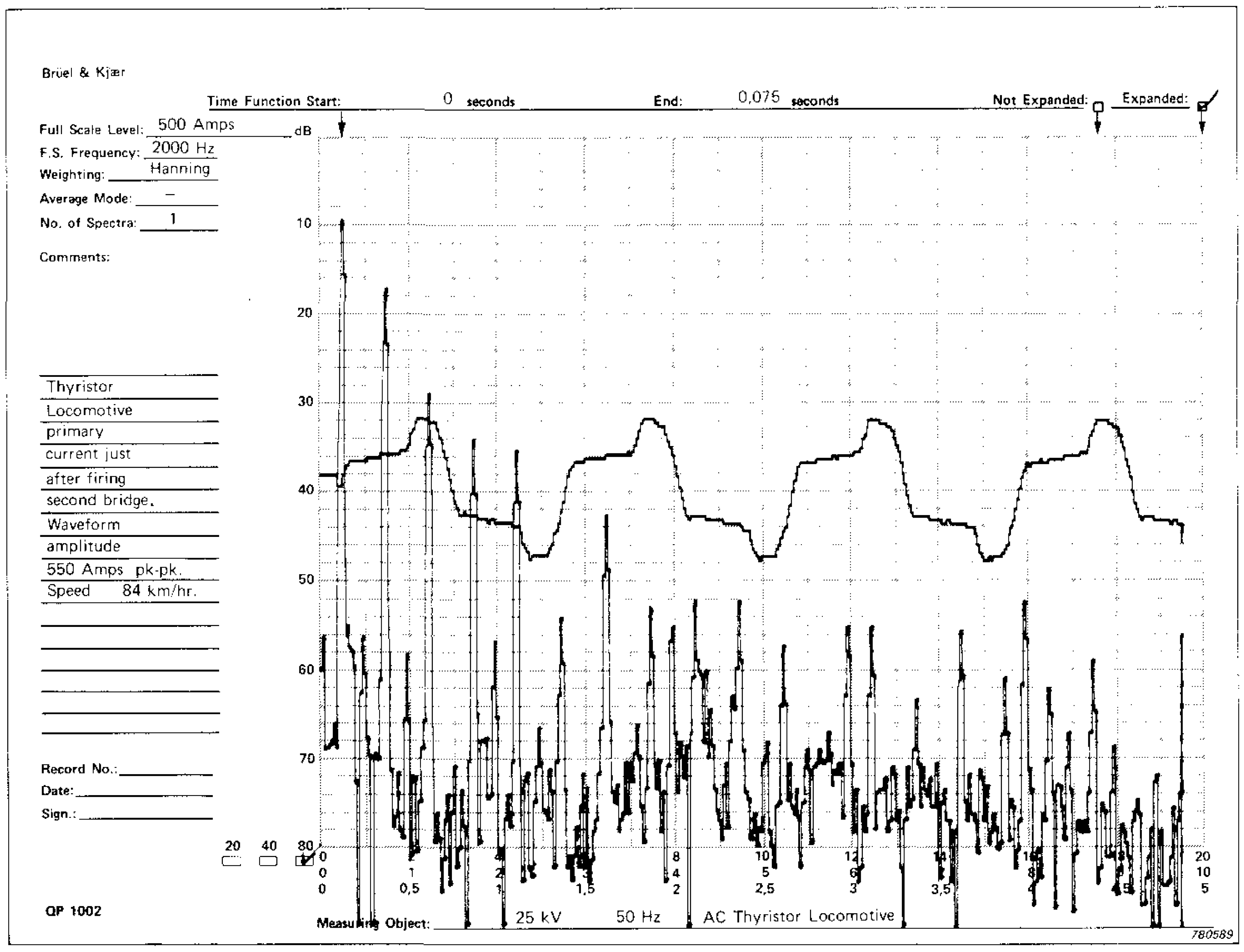
When a harmonic enters the passband of a narrow-band filter, the output of the filter does not instantaneously build up — it takes a finite time t_R of the order of 1/B seconds. Analysis shows that for a typical analyzer filter,

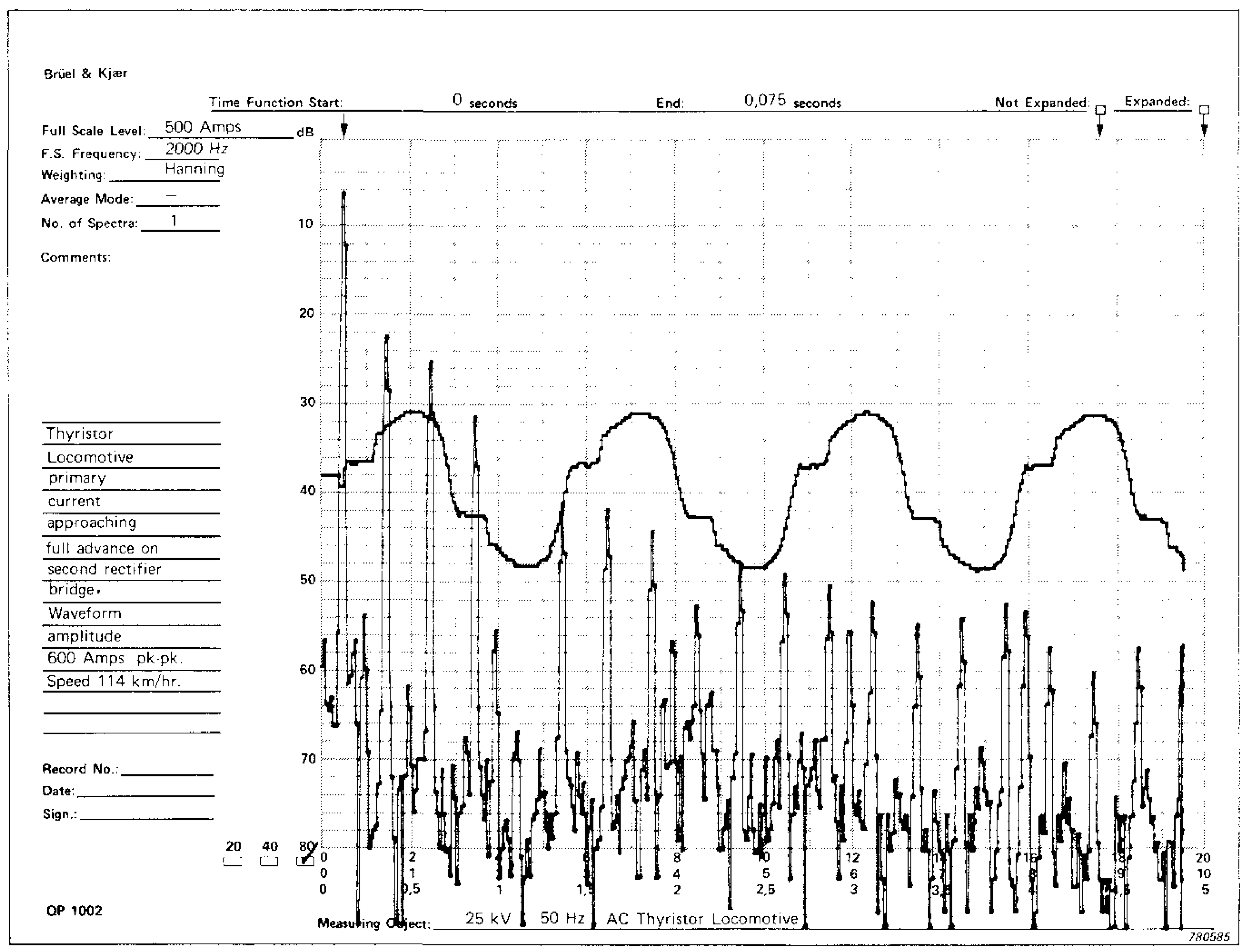
$$t_R = \text{approx.} \frac{4}{3} \times \frac{1}{B}$$

$$= \frac{4}{3} \times \frac{3}{2f}$$

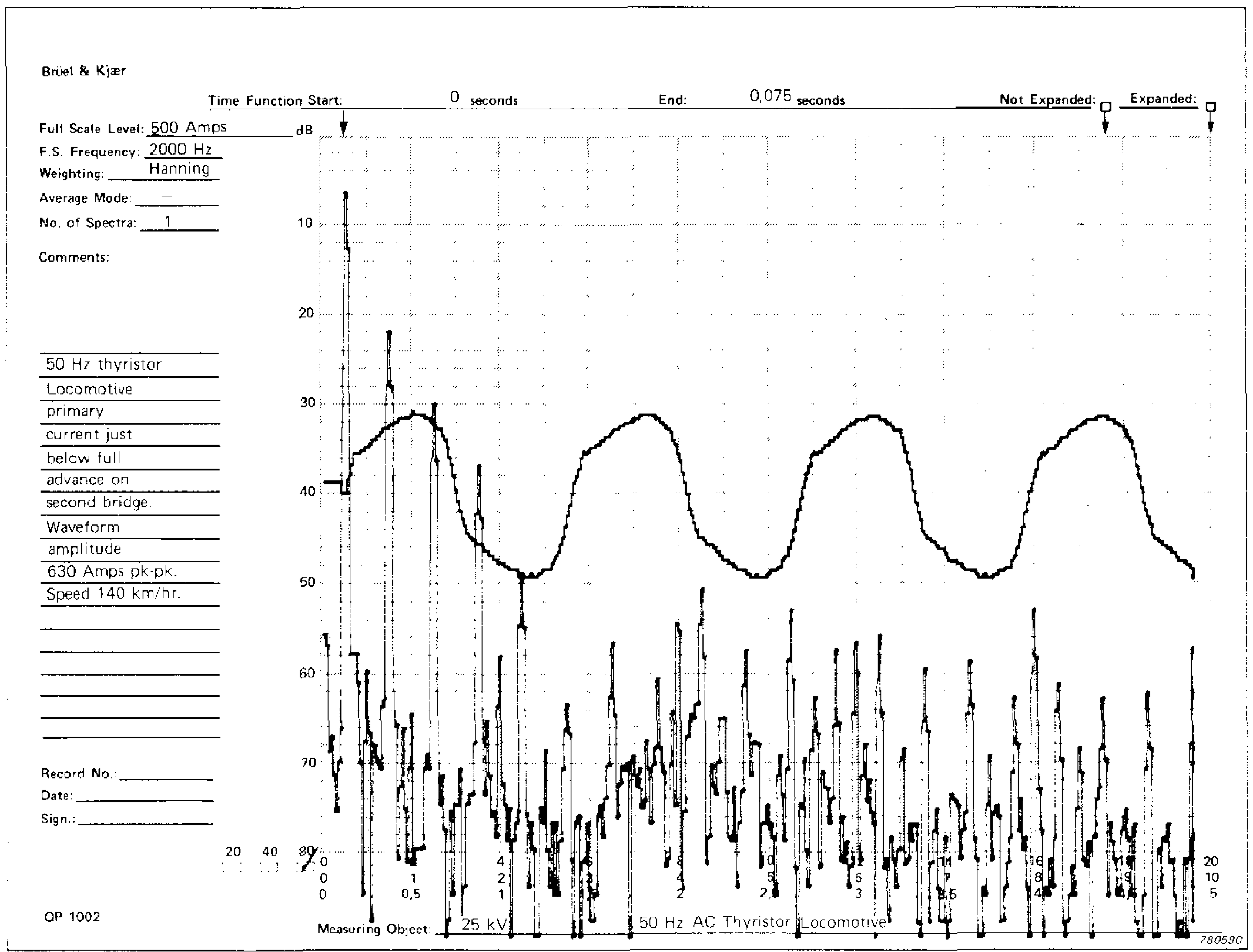
$$= \frac{2}{f} \text{sec}$$

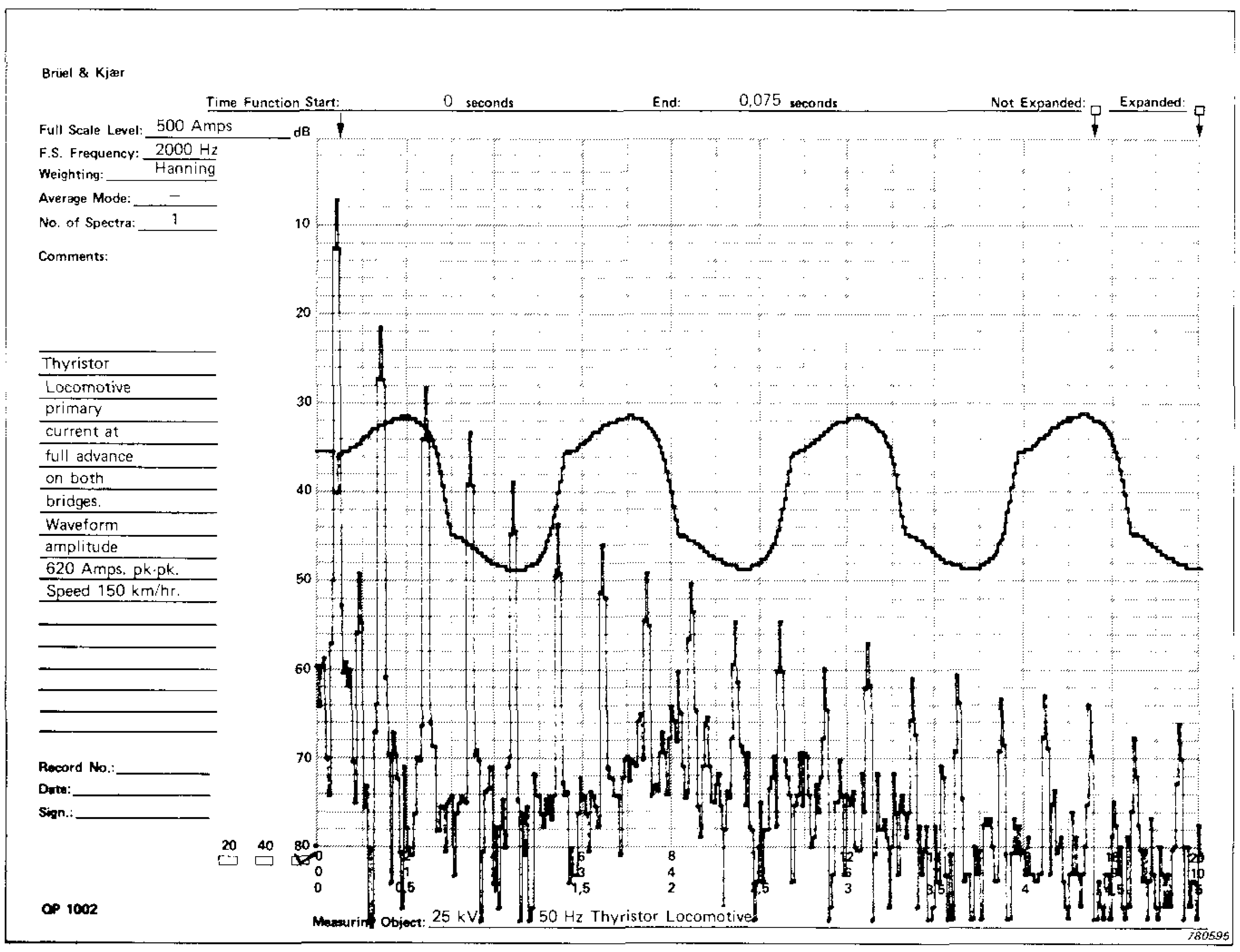
In order to permit the RC filter to build up to maximum level, each harmonic must remain within the passband B a further length of time depending on the time-constant RC.





In these two plots, both rectifier bridges on the thyristor locomotive have begun to conduct. Note that the Type 2031 provides a logarithmic (dB) amplitude scale, but a linear frequency scale. The advantage of the former is the wide range of measurement possible - the 35th harmonic, for example, is 60 dB below the 500-Amp reference level in the lower figure, i.e., 0,5 Amp, which would be insignificant on a linear scale. The advantage of a linear frequency scale is that it gives uniform spacing of harmonics; in these figures the frequency range is 0 to 2000 Hz





Although the primary current waveforms in these two figures are very similar, the dip in the 11th harmonic in the upper trace indicates that the second bridge had not quite reached full conduction (i.e., phase-advance). The lower figure shows full full conduction on both bridges, i.e., diode operation of the locomotive

To get an accurate and undisplaced display, the total time for which each harmonic lies within the 3 dB passband B (which is known as the dwell time, t_D) should be about four times t_R:

$$t_D = \text{approx. } 4t_R$$

$$= \frac{8}{f}\text{ sec;}$$

but $t_D = \frac{B}{S}$, by definition,

$$= \frac{2f}{3S}\text{ sec;}$$

therefore $S = \frac{2f}{3t_D}$

$$= \frac{2f}{3} \times \frac{f}{8}$$

$$= \frac{f^2}{12}.$$

Duration of one sweep =

$$= \frac{n_{max} f}{S}$$

$$= n_{max} f \times \frac{12}{f^2}$$

$$= \frac{12 n_{max}}{f}\text{ sec.}$$

Suppose the signal being analyzed is the supply current from a locomotive or EMU on an AC electrified system, and the train is accelerating uniformly from rest. You can see from the diagram of the pattern of odd harmonics generated by an ideal rectifier that as the phase of one thyristor bridge is advanced from 0° to 180° the harmonic amplitudes fluctuate periodically between zero and a maximum level dependant on harmonic number, n. The total number of complete fluctuation cycles is n/2, for each harmonic (by inspection). Thus if the train takes t_F seconds to advance from 0° to 180°,

duration of one fluctuation cycle =

$$= \frac{2t_f}{n}$$

To prevent aliasing (spurious sampling effects), the duration of one sweep must be significantly shorter than the duration of one fluctuation cycle for the highest harmonic observed $n_{max}\,f$. For example, if the sweep rate were only twice the fluctuation rate, it would be possible for each sweep to coincide with identical levels on the "up" and "down" portion of the same fluctuation, and the display would indicate no fluctuation at all. It is advisable to sweep at a rate about four times faster than the fastest fluctuation rate required to be observed, so

$$4 \times \frac{12n_{max}}{f} = \frac{2t_F}{n_{max}};$$

therefore

$$n_{max}^2 = \frac{2ft_F}{48} = \frac{ft_F}{24};$$

i.e.,

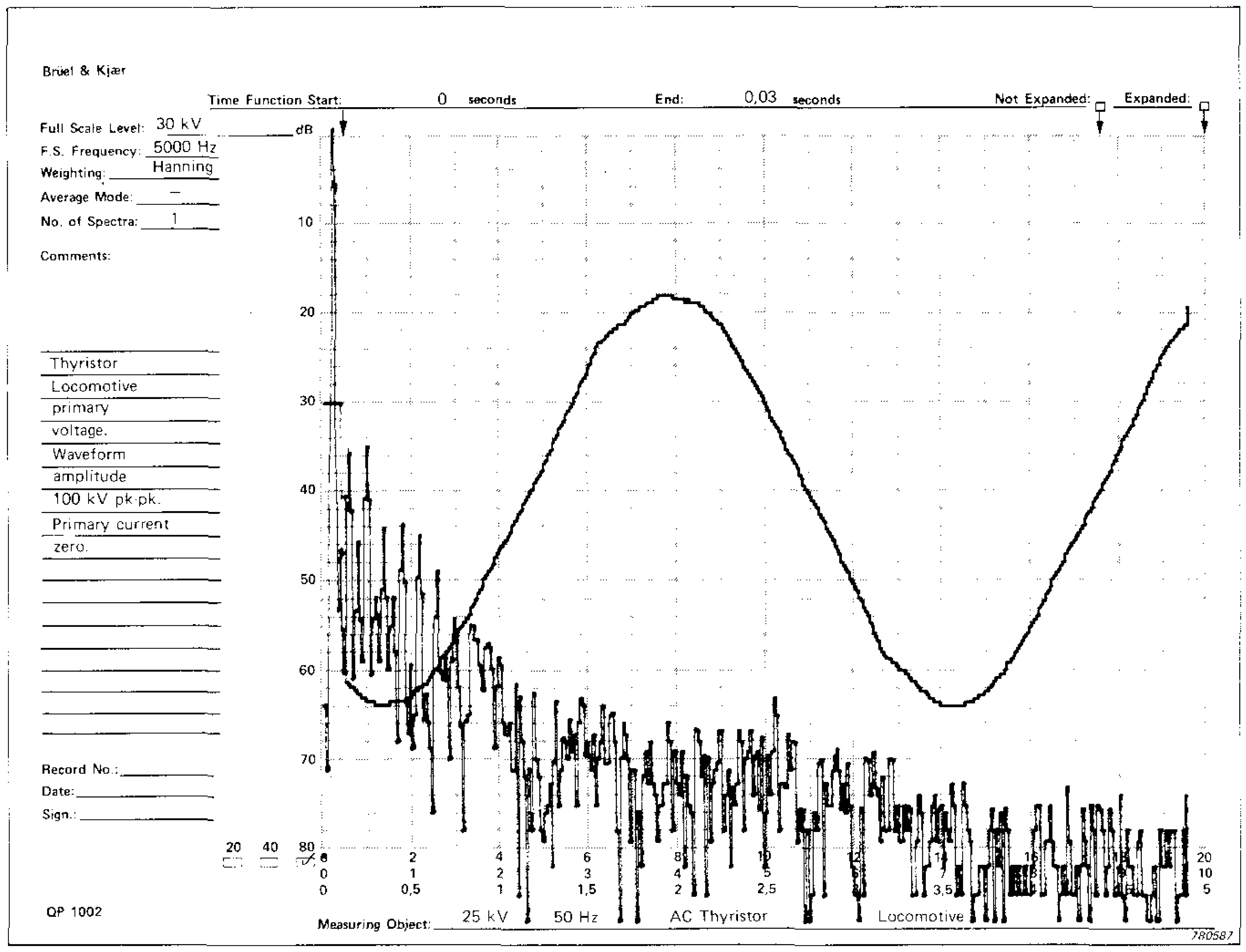
$$n_{max} = 0{,}2\sqrt{ft_F}$$

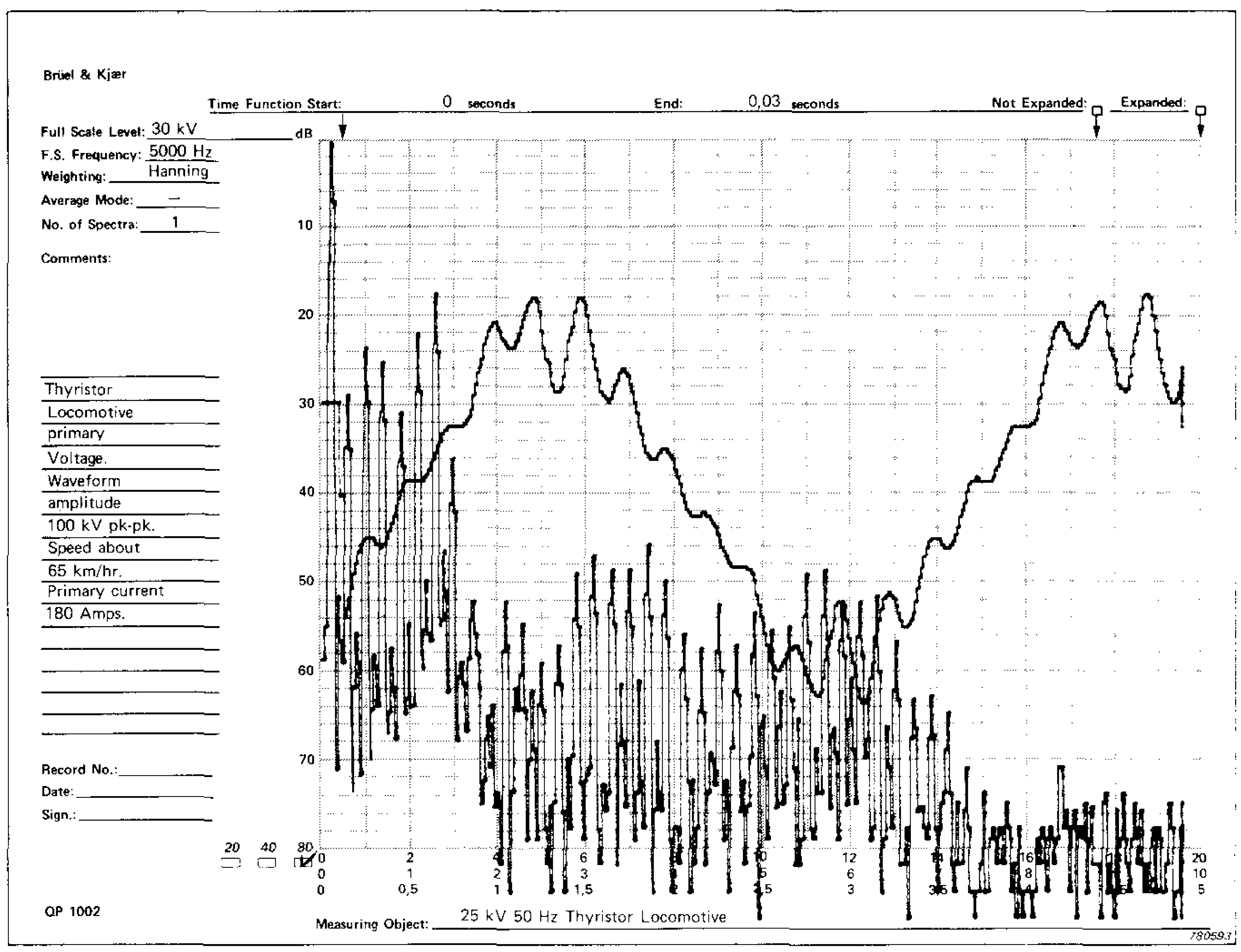
approx.

Thus for $f = 50\,\text{Hz}$ and $t_F = 25$ seconds, $n_{max} = 7$, which is 350 Hz. Although a locomotive might accelerate as slowly as this, an EMU would normally advance from 0° to 180° on one rectifier bridge much more quickly, so the number of harmonics which may be usefully observed with a swept-frequency analyzer is very restrictive.

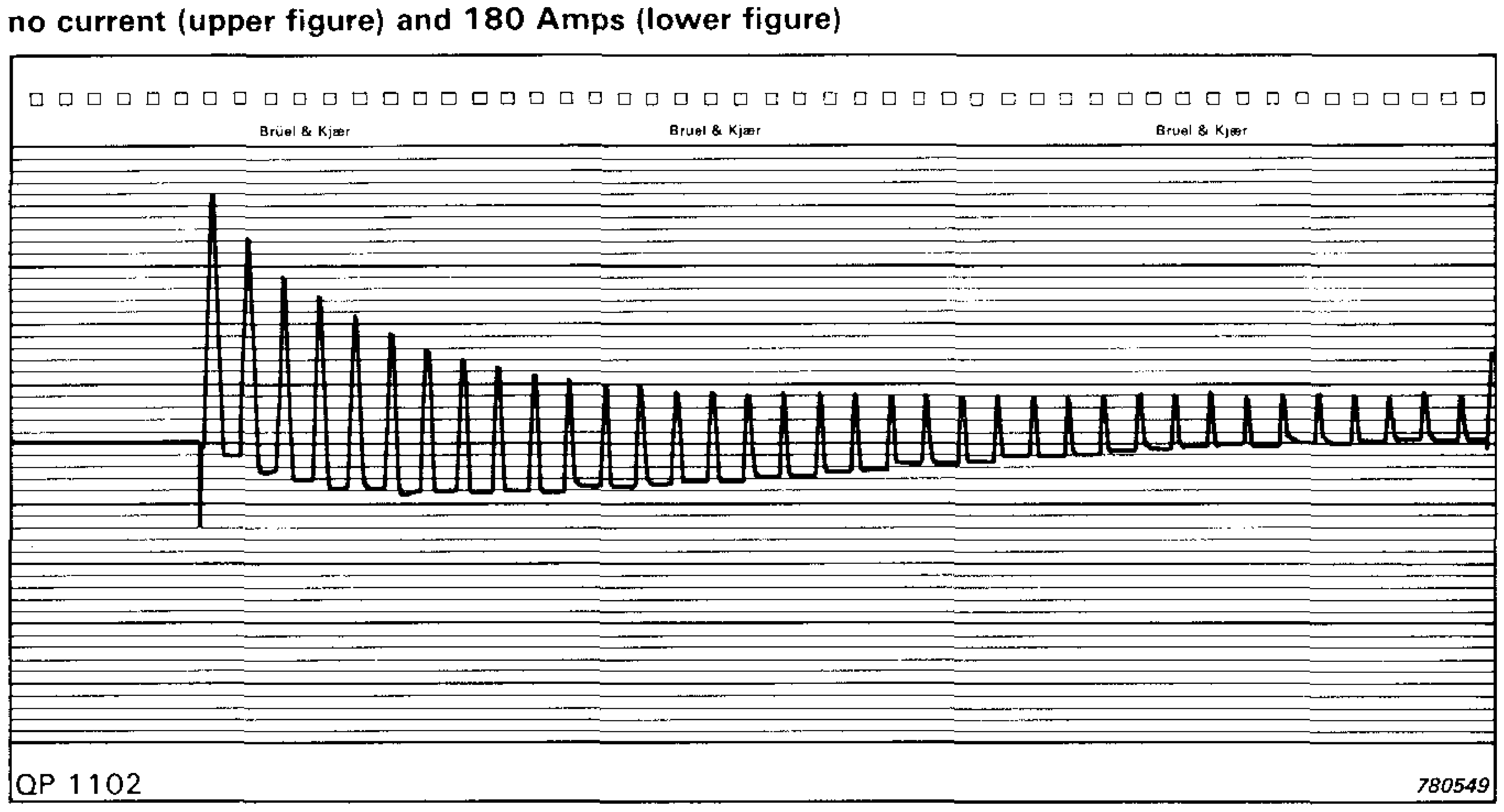
This is because the signal for analysis from an accelerating train is what is known (quite logically in this instance!) as a Non-Stationary Signal.

It does not help to play the tape more slowly, either, since the bandwidth of the filter has to be reduced in proportion and so does the sweep rate.

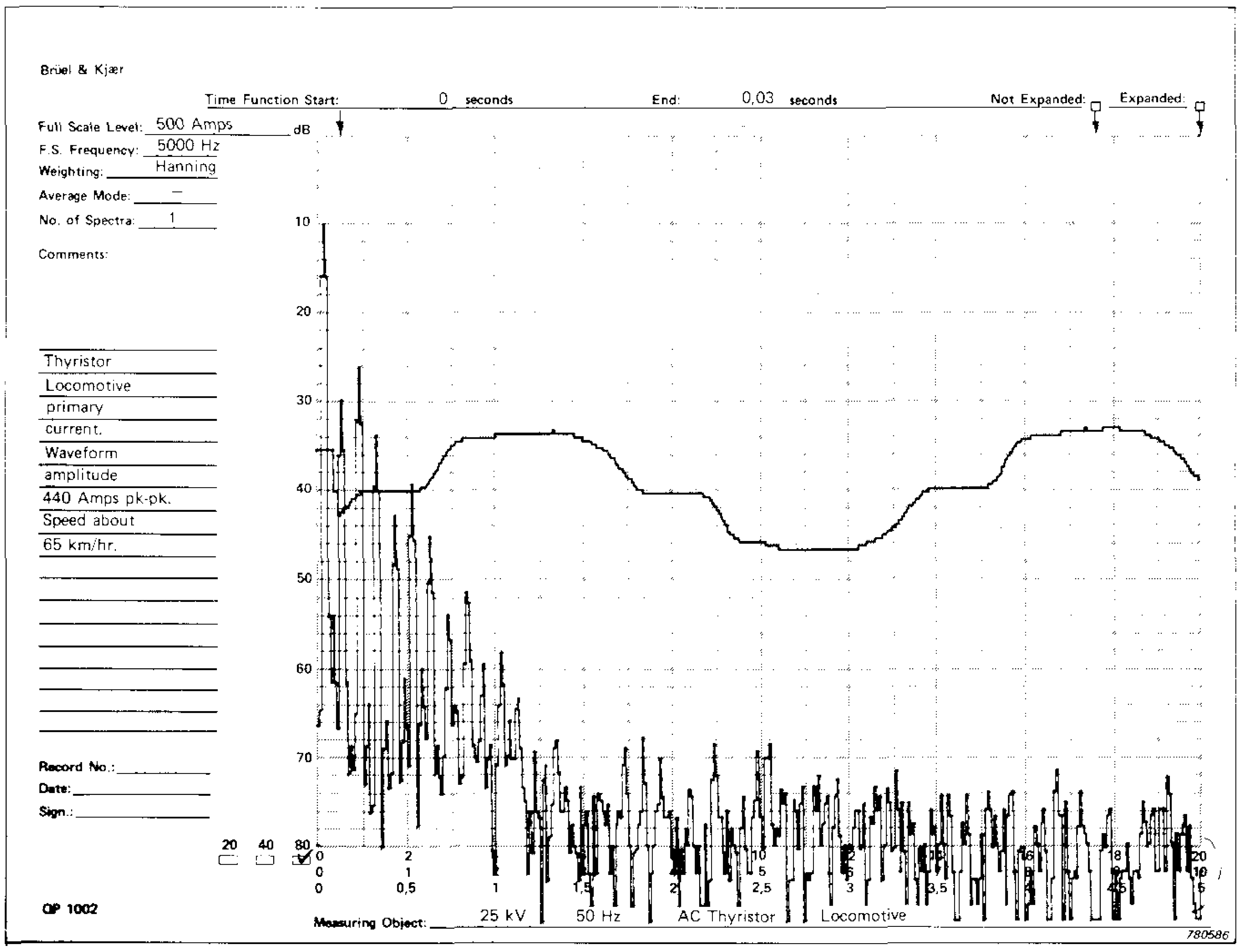




Primary voltage waveforms and spectra, showing the effects of a thyristor locomotive drawing no current (upper figure) and 180 Amps (lower figure)



Example of the inrush current waveform in a 50 Hz AC traction transformer. The initial peak is 500 Amps



Primary current waveform and spectra recorded at the same instant as the lower of the two voltage records on the opposite page. Note that all three have 0-5000 Hz frequency scales. It can be seen that the 11th harmonic is much more pronounced in the voltage trace than in the current trace, indicating a network parallel-resonance at around 550 Hz

The best that can be done when the only spectrum analyzer available is a swept-frequency analyzer is to contrive a stationary signal by making a tape loop of each part of the signal, or, rather less laboriously, by introducing a B & K Type 7502 Digital Event Recorder, which can perform the same function without moving parts.

However, a much faster, and more informative analysis may be performed using a Type 2031 Narrow-Band Real-Time Analyzer. This instrument will display all the harmonics you are interested in continuously, on a big, calibrated display, and you have to play the tape only once. It will communicate through a standard interface with any one of a number of desk-top calculators, and can be remotely controlled from this calculator. It can output the time-varying spectrum on a suitable hard-copy unit. The display is linear in frequency, so there is no bunching of the higher harmonics where so many line resonances occur, and it is logarithmic in amplitude, with a choice of 20, 40 or 80 dB (× 10, × 100, × 10000) full scale deflection, so you can measure the amplitude of any harmonic, even the weak ones, to better than 10%, without changing any of the settings.

How can the 2031 achieve what is impossible for a swept-frequency spectrum analyzer? The answer is that it is almost all digital in its operation. It divides the signal up into records of manageable length, calculates the Fourier transform of each record length mathematically using the Fast Fourier Transform algorithm, and displays the transform on its screen, while the next record is being stored. It is in effect a dedicated digital computer. Because it takes account of all the signal, it can operate in real time, whereas a swept-frequency analyzer can only sample the signal and in fact disregards most of the information available. The 2031 is real-time only up to 2 kHz, but this is normally enough for traction work, since it will analyze faithfully all the harmonics of 60 Hz up to the 33rd with a 5 Hz bandwidth.

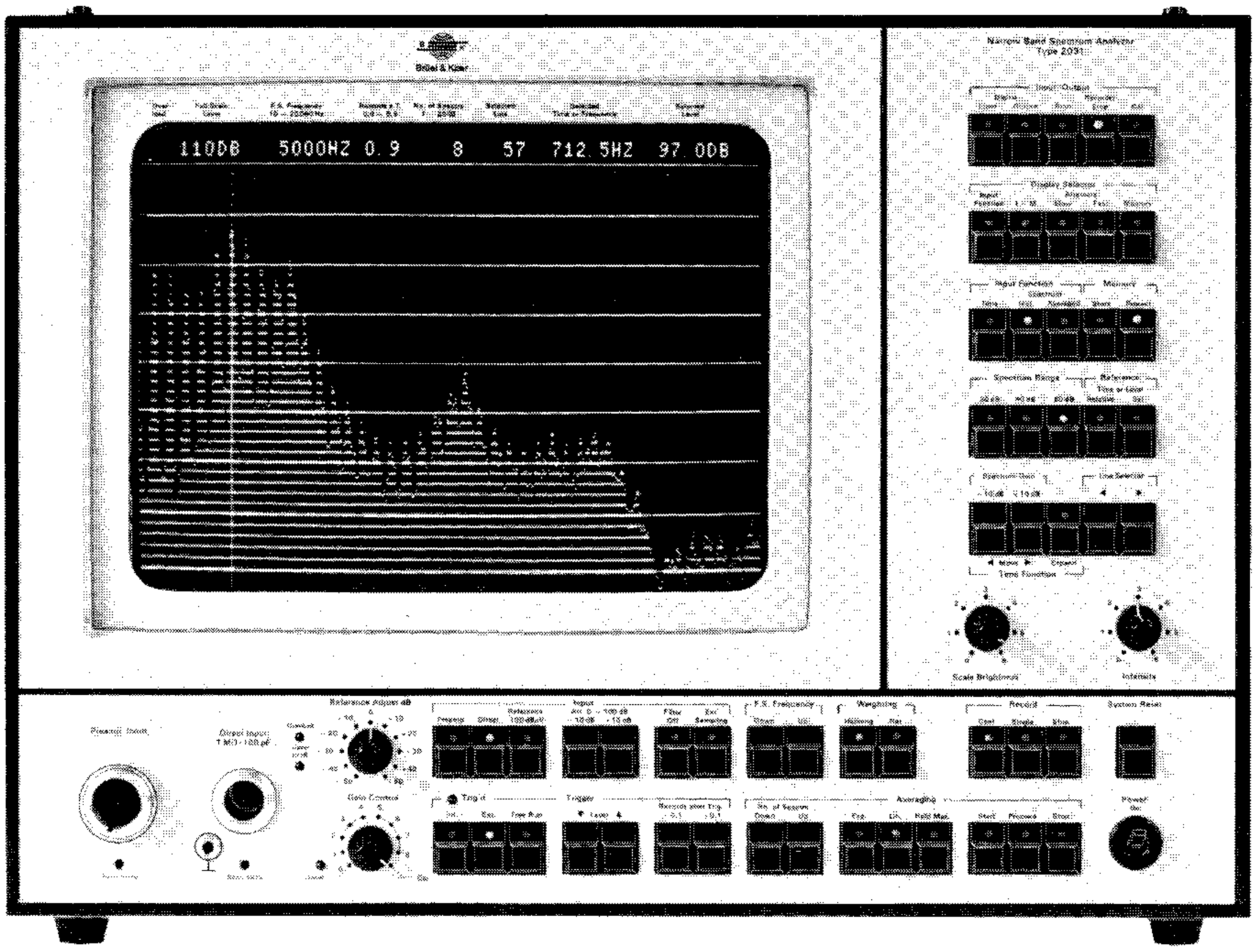
At the same time, the 2031 is a remarkably compact instrument. It is all contained within a single case weighing 22 kg (48,5 lb) and may be used on site if required.

The 2031 will also give you a very informative picture — literally — of transients such as the inrush current on a DC chopper or AC traction transformer. It has all the facilities you would expect for versatile triggering, and to save you having to repeat an event, it stores all the information about the event for as long as you want. You can display not just a precise, calibrated spectrum of the transient, but you can also look at the waveform itself (using the 2031 as a high-quality storage-oscilloscope) and move an electronic cursor across it to make measurements of its characteristics. You can switch from one to the other at will, and decide whether the level of dangerous frequencies is enough to matter or not. You can do it for as many transients as you have bothered to tape-record, without taking up hours of valuable time.

Other features which you might want to know about the 2031 are:

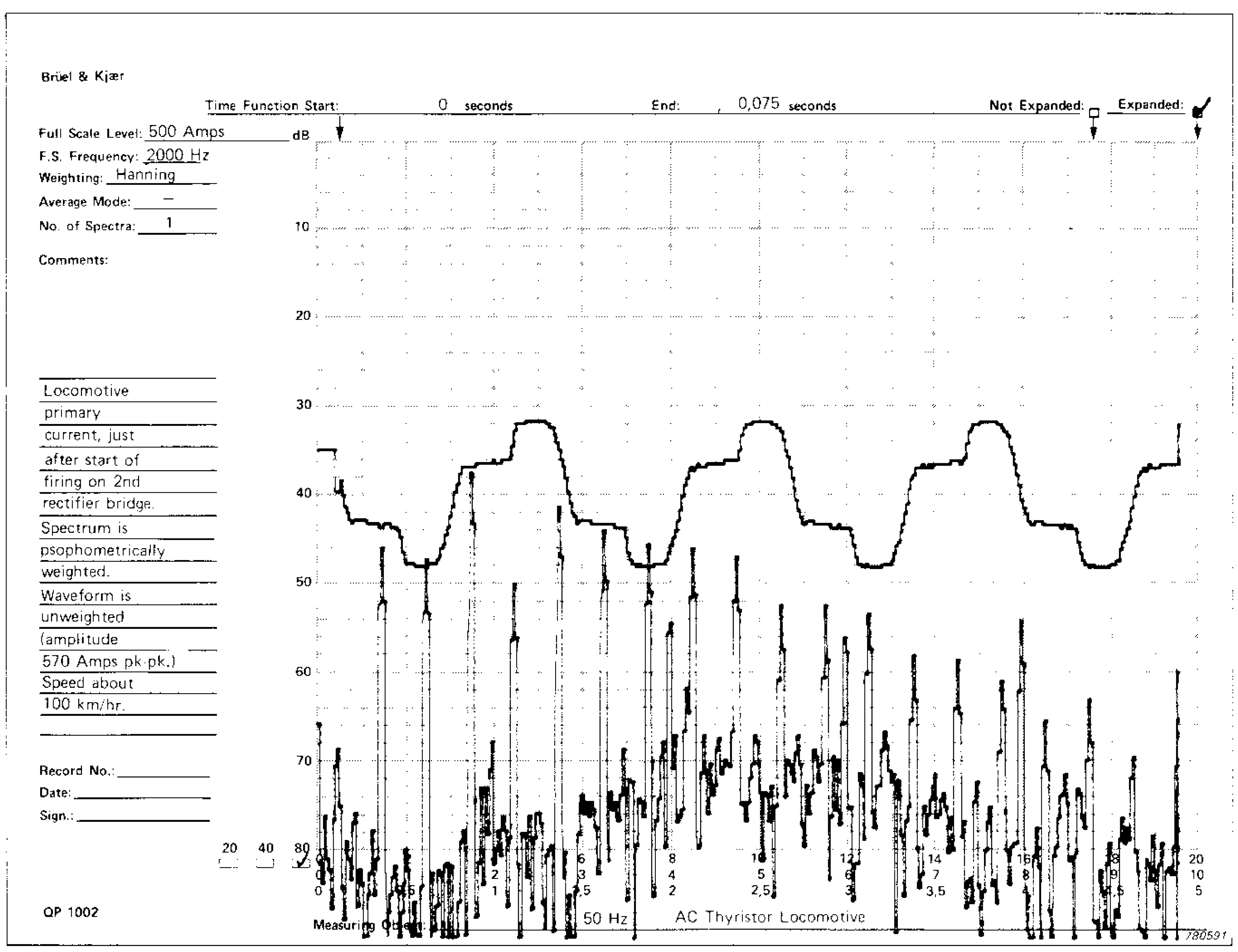
* 400-channel frequency resolution over eleven ranges from 0 to 10 Hz to 0 to 20 kHz in 1—2—5 sequence
* Facilities for displaying time-averaged spectrum and difference between two spectra, one of which may be inputted from an external memory such as a desktop calculator, or held in the 2031's internal memory
* Averaging is user-selected, linear or exponential, over 1 to 2048 spectra
* Alphanumeric indication of all relevant settings displayed along the top of the 11-in low-reflectance screen, including line-selector (cursor) position and level
* IEC/IEEE Std. 488 interface
* Electronic graticule for parallax-free readings
* Analogue outputs to level recorders and X-Y plotters: a complete spectrum can be plotted out on a plotter such as the B & K Type 2308 X-Y recorder in 45 seconds, and the same goes for continuous or transient time-waveforms
* Can be used as a storage-'scope and transient recorder
* Power requirements 100—240 V 50—60 Hz, 120 W approx.

An ideal method of predicting reliably the effects of a new thyristor equipment still on the test bed (especially on AC electrified railways) uses the 2031 Narrow Band Analyzer. The technique consists in going out and recording both the traction supply current (at the train) of an existing traction unit — not necessarily a thyristor vehicle — and the corresponding induced signal in the associated light-current trackside circuits. Recordings should be made at all the locations of interest, including at least one with the vehicle close to the substation (where its behaviour will be similar to test-bed behaviour when it comes to harmonics). Back in the laboratory, the recordings are fed into a 2031 Narrow Band Analyzer, which is used to evaluate and display difference-spectra between the traction current and induced signal. These spectra are in effect transfer-functions of attenuation, from catenary to S & T circuit, against frequency. Since all the trackside components are strictly linear, the spectra represent the absolute characteristics of the electrification system at those locations, independent of the type of vehicle used. The spectra may be plotted very quickly on the Type 2308 X-Y recorder for subsequent use. If a desktop calculator with a reasonable size store is available, the spectra may be fed into this with advantage. The next step is to record and analyze the traction current of the new thyristor equipment under test on the test-bed. This analysis will produce quite a good picture of the "harmonic signature" of the equipment — and by subtracting from it the difference-spectra obtained previously, either visually or digitally (with the help of the calculator), it is possible to see what level of each harmonic might be induced in the S & T circuits at each location by the new thyristor traction unit.



Type 2031 Real-Time Narrow-Band Frequency Analyzer

The reason this method is more suited to AC electrification applications is that conventional diode rolling-stock generates most of the harmonics likely to occur, but at different level from thyristor equipment. The 2031 Analyzer has a 70 dB dynamic range (with a 9 dB overload margin), so it can readily display the amplitudes even of very weak harmonics. It might appear that if the signal to be analysed has been recorded on a tape-recorder with 44 dB dynamic range (i.e. the Type 7003), most of this benefit is lost. However, the noise on the tape is mainly spread out uniformly over the 12 kHz of its bandwidth, and if we effectively pass this through a narrow-band filter — as the 2031 does when it performs harmonic analysis — the noise level in any given narrow band falls dramatically, making it entirely possible to extract individual harmonics 30 dB (one-thirtieth) below the level of broadband noise.



Example of primary current waveform and psophometrically-weighted frequency spectrum, recorded just after the start of conduction of the second rectifier bridge

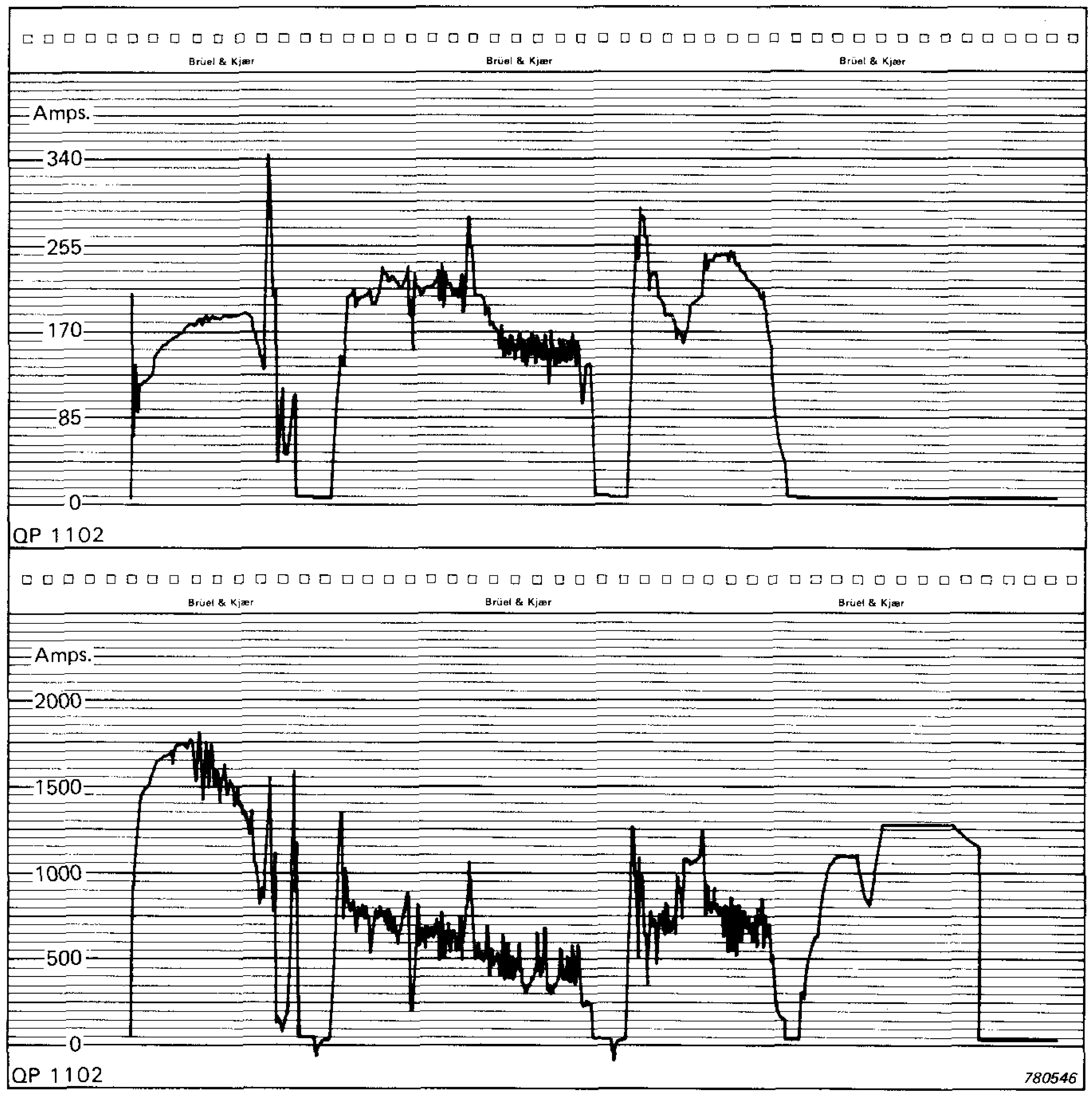
Log the tape recordings

A tape recorder always records in real time, and a sensible and systematic commissioning team who record all the tests they carry out, on the test-bed and on the track, will end up with a lot of tape. To remain useful over a period of months or years, this tape must be systematically logged — and on the basis that one picture is worth a thousand words, it is much more useful to produce a sequence of plots of what is going on on each tape, than to write out a long description on the tape box.

Brüel & Kjær manufacture graphic hard-copy units for both of the principal duties likely to be encountered in this kind of work. For time-varying functions such as traction current, train speed, and psophometric current, three level recorders are available, Types 2306, 2307 and 2309. For plotting two related variables such as harmonic amplitude against harmonic frequency, or psophometric current against speed, an X-Y recorder, Type 2308, is available. The latter is also better (because of its paper size) for making permanent records of time-waveforms, for subsequent comparison. To some extent, of course, either kind of instrument can be used for both purposes.

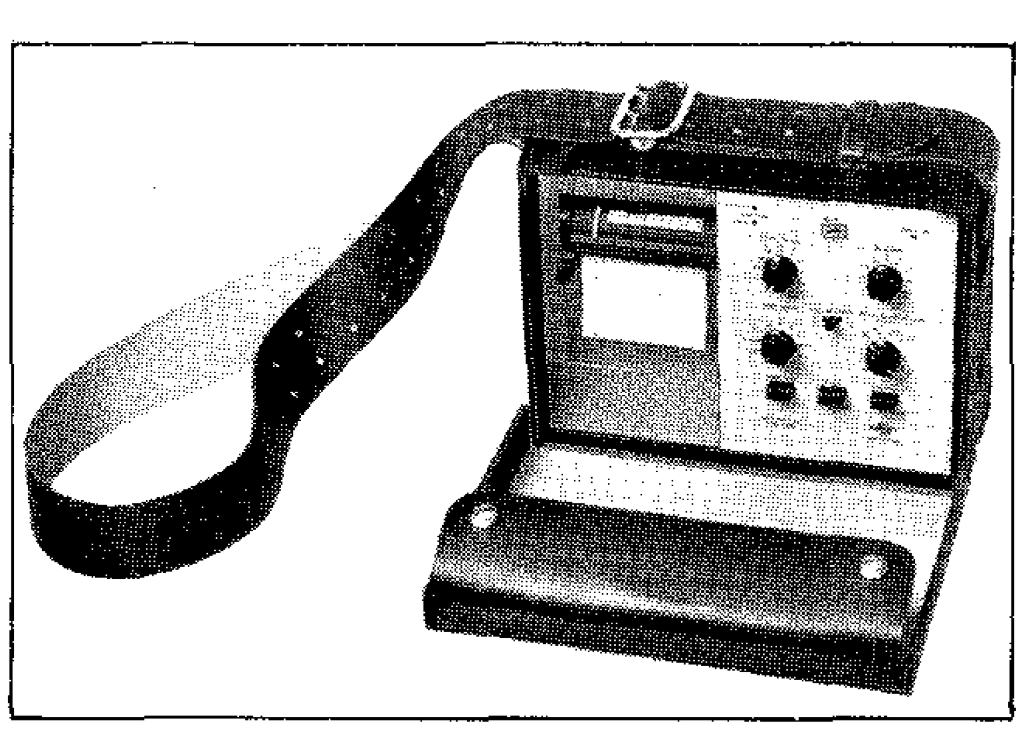
The advantage of the B & K level recorders is that they may be used for recording DC or AC signals, since they all incorporate true RMS detectors to convert an incoming AC signal into a pen deflection. The 2307 also has peak and average detectors as alternatives. All recorders also provide for logarithmic recording to give constant resolution over the whole dynamic range. If linear recording is required of AC signals (such as traction current on AC electrified equipment), it is necessary to use an external measuring instrument (such as the psophometer in its unweighted mode) in conjunction with the Types 2306 and 2309.

The Type 2306 and 2309 have their paper throw controlled by stepping motors. If speedometer or tachometer pulses are available on the train, these pulses may be used to regulate the paper throw in proportion to distance travelled along the track, instead of logging the signal at a uniform time rate.



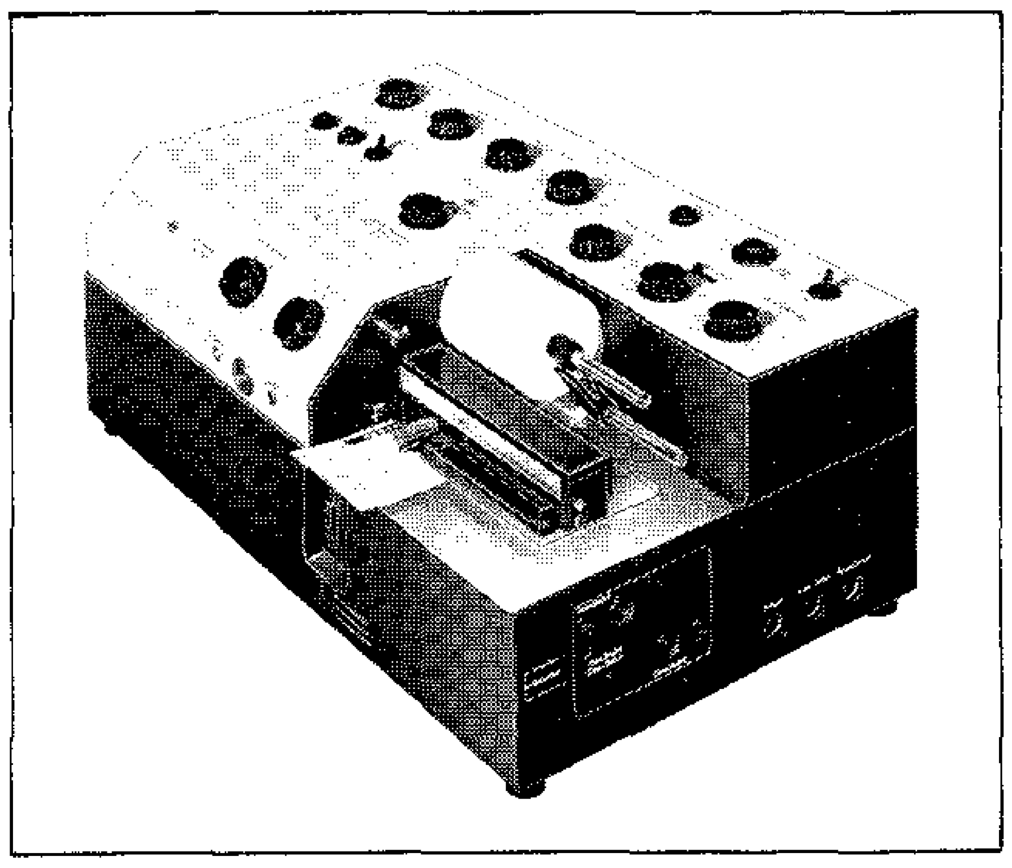
Extracts from tape recording of thyristor locomotive trial, logged using a Type 2307 Level Recorder. The upper trace records RMS pantograph current over a period of about 2 minutes, and the lower trace records current in one armature during the same period. Note the application of electric rheostatic braking (zero pantograph current) at the end of the record

All the B & K level recorders write with disposable fibre pens on continuous calibrated paper from a roll. The Types 2306 and 2307 also offer the option of writing with sapphire styli on wax-coated paper. These techniques result in high-contrast, instantaneous records requiring no subsequent processing. Other features of the recorders are set out below.



Type 2306 Portable Level Recorder

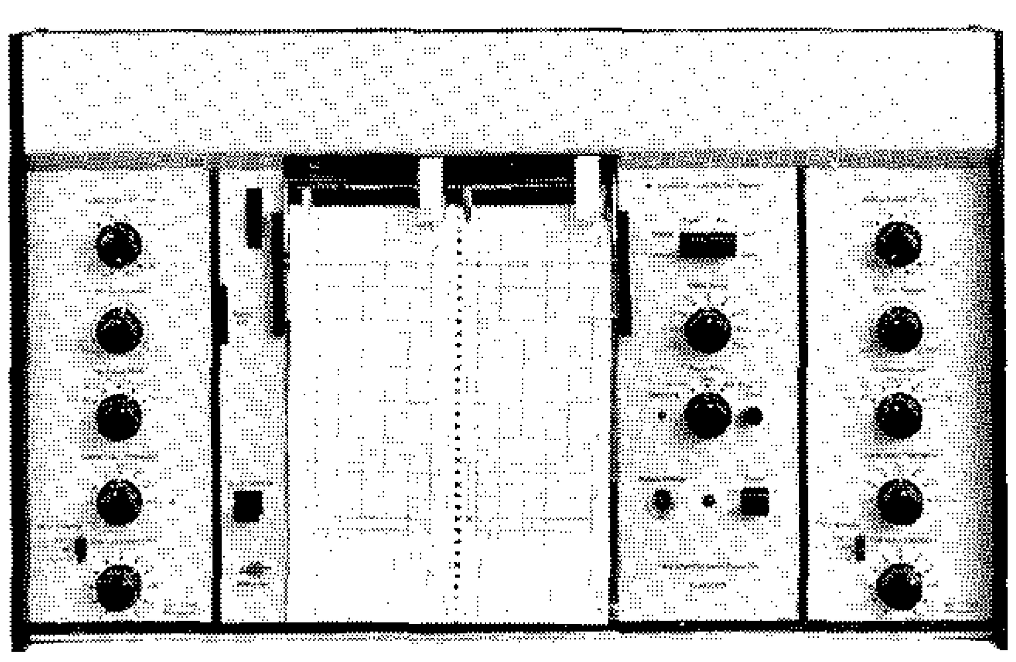
Type 2306:
* Fully portable battery operation, from built-in dry or rechargeable NiCd cells, or operation from separate mains supply such as Type 2808 or 6—12 V DC 500 mA max.
* Weight only 3,5 kg (7,7 lb), dimensions only 180 × 245 × 110 mm (7,1 × 9,6 × 4,3 in)
* Built-in meter to monitor supply condition
* 8 fixed paper speeds 0,01 to 30 mm/s, plus external TTL pulse train or voltage ramp (using Type WB 0228 paper drive unit)
* 4 writing speeds 16 mm/s to 250 mm/s
* Can interface with Type 4426 Noise Level Analyzer for, e.g. statistical analysis of telephone interference
* Remote paper stop/start



Type 2307 Level Recorder

Type 2307:

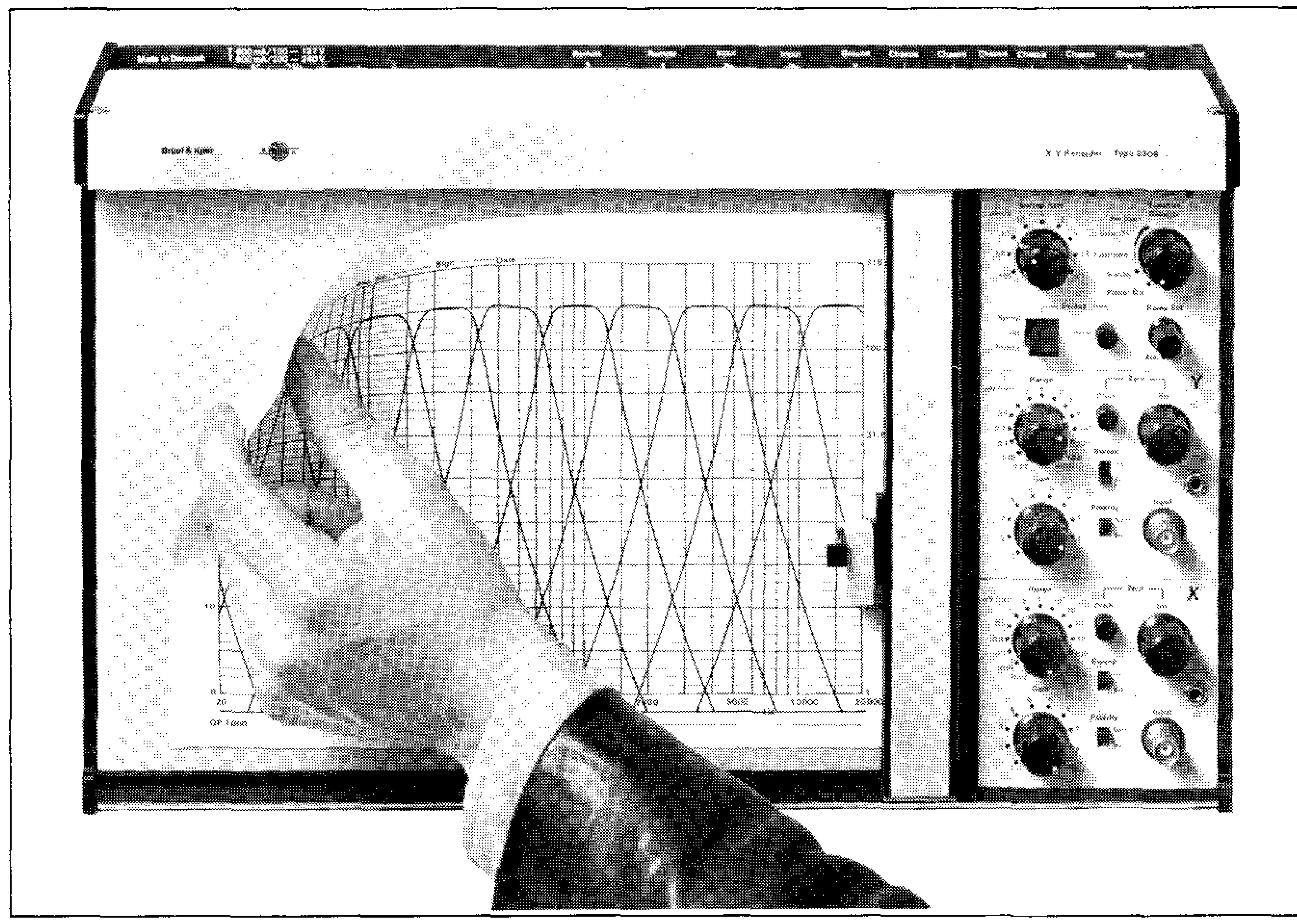
* Very versatile recorder with maximum of facilities for laboratory use
* 12 fixed paper speeds from 1,08 mm/hour to 100 mm/s, plus external voltage ramp, 250 mm max. continuous throw
* 2 chart widths, 50 or 100 mm recording space
* 15 different writing speeds: 4 mm/s to 2 m/s (100 mm width) or 2 mm/s to 1 m/s (50 mm width)
* Remote control of paper start-/stop, automatic stop, external automatic stop, pen lift and event marking



Type 2309 Two-Channel Portable Level Recorder

Type 2309:

* Two-channel two-pen recorder for simplified logging of multi-channel tape recordings — plot both train speed and traction current as functions of time, for example
* 8 fixed paper speeds 0,01 to 30 mm/s, plus external paper control
* 4 writing speeds 16 mm/s to 250 mm/s
* 50 mm writing-width per channel
* Extensive remote control facilities, including pen lift
* Built-in ramp and calibration signal
* Automatic stop after 250 mm paper advance if required
* Operation from 6 dry cells or rechargeable cells, mains converter Type 2808 or external 6,5 to 15 V DC supply

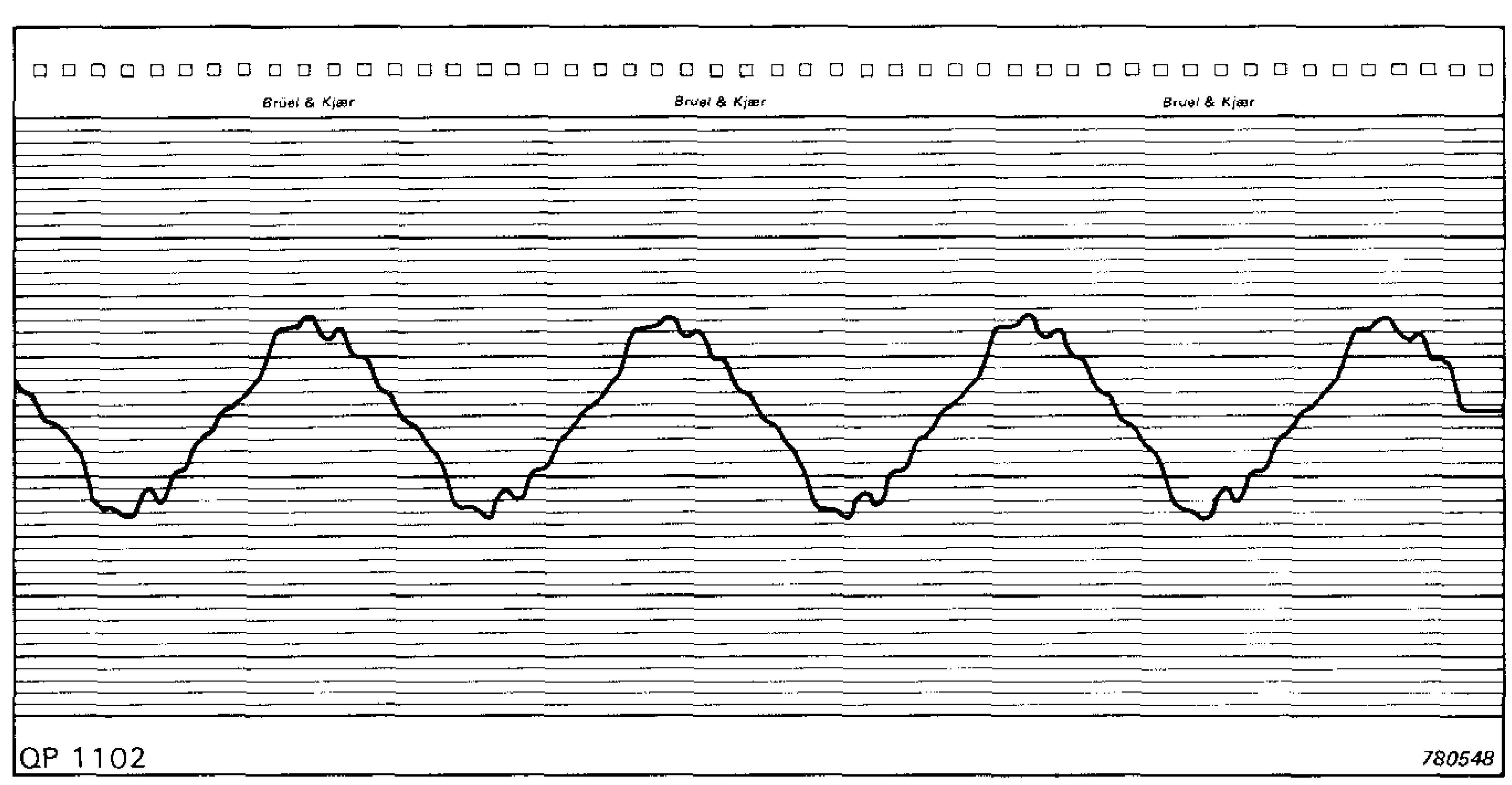


Type 2308 X-Y Recorder

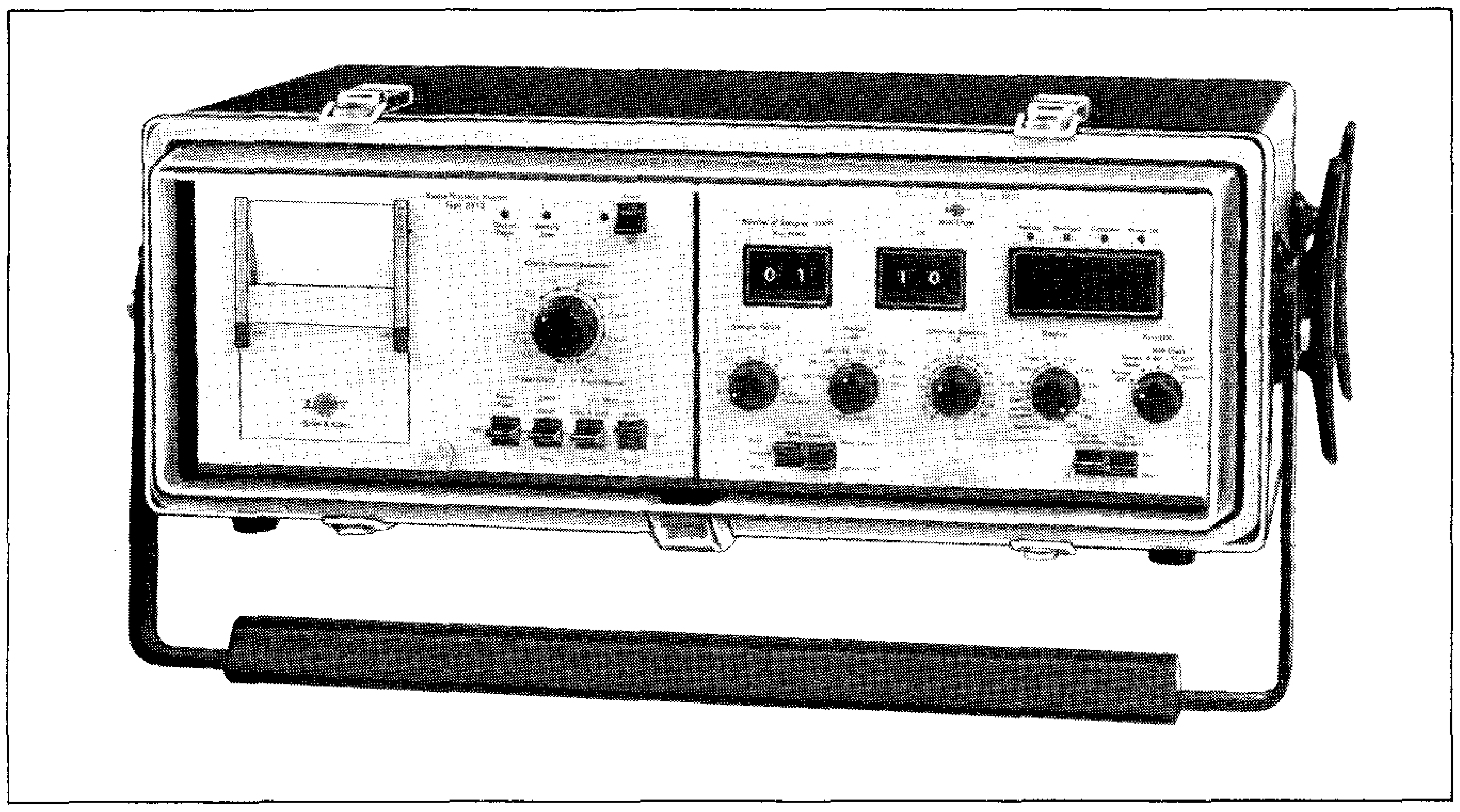
Type 2308

Although the B & K level recorders are all suitable for plotting frequency spectra, and also waveforms in conjunction with a suitable means for slowing down the time scale (such as the Type 7502 Digital Event Recorder or the 2031 Narrow Band Analyzer), larger plots with greater resolution may be obtained from the Type 2308 X-Y Recorder. This instrument offers the following features.

* Very large writing area 185 × 270 mm (7,25 × 10,6 in)
* Fast pen displacement rate 1,0 m/s and acceleration 100 ms^{-2} with less than 1% overshoot
* 15 calibrated X and Y input sensitivities 20 μV/mm to 1 V/mm
* 9 calibrated sweep rates 0,2 to 100 mm/s from internal sweep generator with ramp voltage output 0 to 10 V having ± 10 V continuously adjustable offset
* Floating, reversible inputs with 1,0 MΩ impedance and continuously variable offsets
* Electrostatic paper hold
* Versatile remote control and synchronisation, including pen lift (the latter automatic at power-off)
* Disposable fibre pens



Typical traction supply voltage waveform during the passage of a thyristor locomotive, showing the presence of line resonance. Frequency = 50 Hz. 1 division = 5 kV



Noise Level Analyzer Type 4426 and Alphanumeric Printer Type 2312 combined in a waterproof carrying-case KA 2000

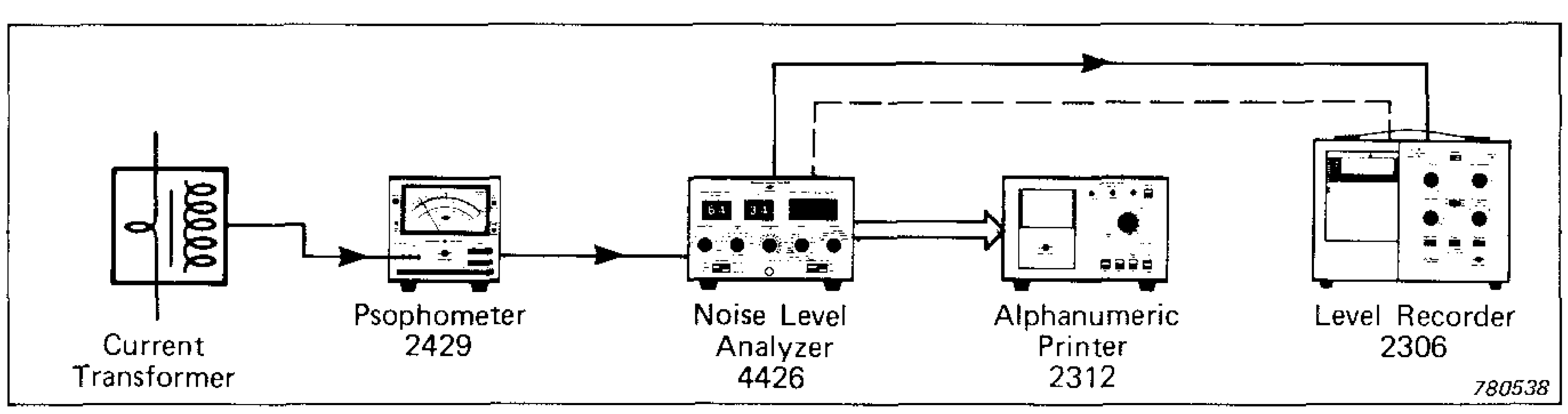
Statistical analysis of psophometric noise

The annoyance caused by any kind of noise experienced in a human environment (as opposed to say, an electronic circuit) depends not only on its level and quality, but on its statistical properties — the proportion of time for which it exceeds the acceptable level, for example. This applies to psophometric noise in a telephone circuit, once it reaches the subscriber's handset. Any telephone network is subject to occasional bursts of interfering noise which interrupt conversation but do not prevent it. There is no sense in trying to reduce the level of train-induced noise, which fluctuates considerably as trains come and go, below the statistical level of noise from other sources.

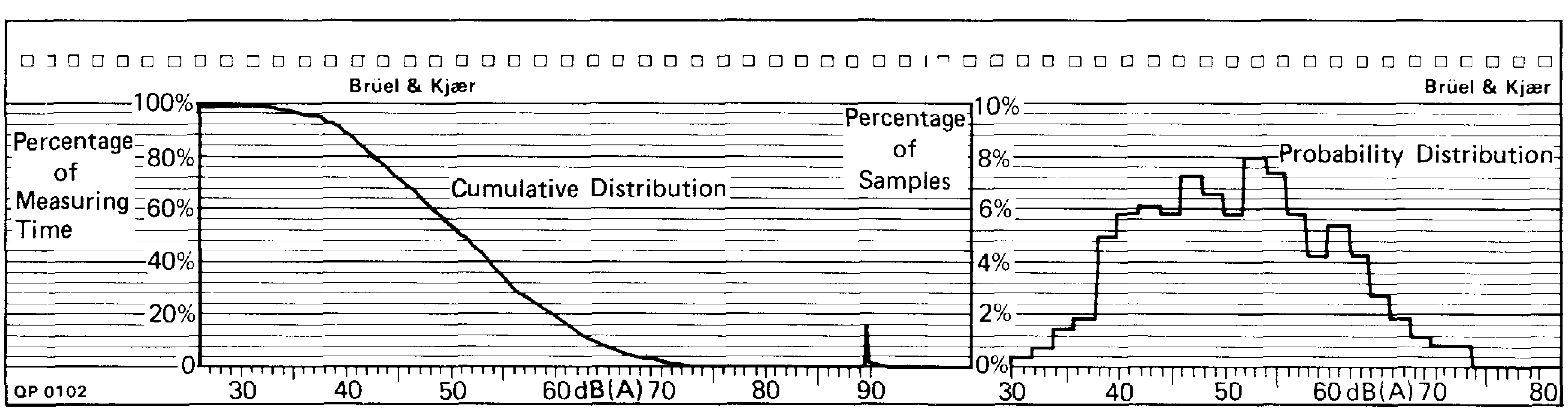
Brüel & Kjær manufacture a Noise Level Analyser, Type 4426, which has been designed for precisely this kind of task. Although its main use is the analysis of community noise out in the field — for which purpose it is made very portable (with battery operation) — it is no less suited to the analysis of psophometric noise in a telephone circuit or a traction supply. It accepts AC or DC signals from measuring instruments such as psophometers, and at the end of each sampling period (user selected from 0,1 to 10 seconds) it grades them according to level and stores the result of the grading in a digital memory. The memory is large enough to accommodate 65000 samples — up to 180 hours — and the instrument may be interrogated manually at any time without interrupting the sampling and recording process.

The Type 4426 has a built-in digital display, but in most applications it is used to output data to a hard copy unit. It can plot cumulative distribution curves and probability distribution histograms on the Type 2306 level recorder, or print them out in accordance with a user-programmed routine on the alphanumeric printer type 2312.

All these instruments are battery operated and very portable, so they can easily be used on a test-bed. It is a common contractual requirement, for multiple-unit rolling-stock especially, to put the traction equipment through tests on the manufacturer's premises which include a simulation of loading conditions experienced on the actual railway, and these tests include evidence of the psophometric component of line current in the case of AC EMU's. A good way to obtain or supply that evidence is to connect up a Type 2429 Psophometer, a Type 4426 Noise Level Analyzer and a Type 2312 Alphanumeric Printer.



Arrangement of equipment for logging statistical properties of psophometric current



Recording of Cumulative Distribution curve and Probability Distribution histogram made on the portable Level Recorder Type 2306

Special problems with DC choppers

When thyristors are used to control the traction motors on DC electric trains, the electronic circuit on the train has to produce its own switching cycle. Because it 'chops' the traction current on and off very fast — faster than the corresponding commutations of an AC thyristor equipment — it is known as a "chopper". As mentioned in the Introduction, thyristors are harder to turn off than to turn on, and extra circuitry known as the commutation circuit is needed. If this commutation circuit fails to function, the current in the chopper will build up very rapidly until either a fuse blows or all the thyristors fail, or both. No matter how much care is taken at the design stage, there are always variables which are not easy to predict, and consequently the early test-bed weeks in the life of any DC thyristor equipment are dominated by transient events associated with switching on and switching off. Furthermore, even when all is working well, the main feature of DC chopper circuits is that for much of each chopping cycle nothing happens, and when it does, it happens quickly.

These characteristics make it difficult to measure and investigate what is going on using an ordinary oscilloscope. Even a storage-'scope with a long-persistence phosphor is of limited use because the event to be studied has to be repeated several times to get the trigger level, Y-channel gain and sweep rate just right — and this is not at all easy when the event is not repetitive. Even when you have captured the event, the only way to expand the trace is to record it again with different settings.

One way round this problem is to tape record the event and keep playing it back through a storage-'scope. This is more flexible, but nonetheless a clumsy procedure. If the event occurs unpredictably, the tape-recorder has to be kept running all the time. For recording and displaying such events, what is needed is a short tape-loop which records only the last few seconds. Provided the tape-recorder has an erase-head, it can be arranged to record and erase continuously, and stop a second or so after the event to be studied. There is then available a record of what happened both before and after the event, on the tape-loop, which may be played back through a storage oscilloscope to give a continuous trace of the event for display and measurement. Furthermore, the display may be expanded at will, and the tape loop retained for subsequent analysis such as output to a graphic plotter, such as the B & K X-Y Recorder Type 2308.

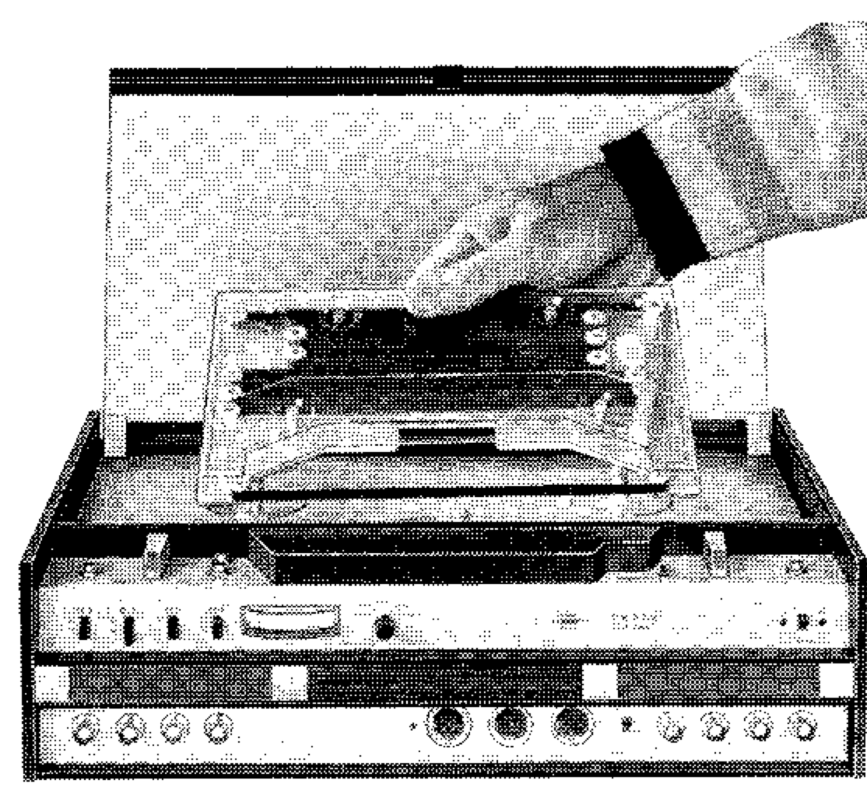
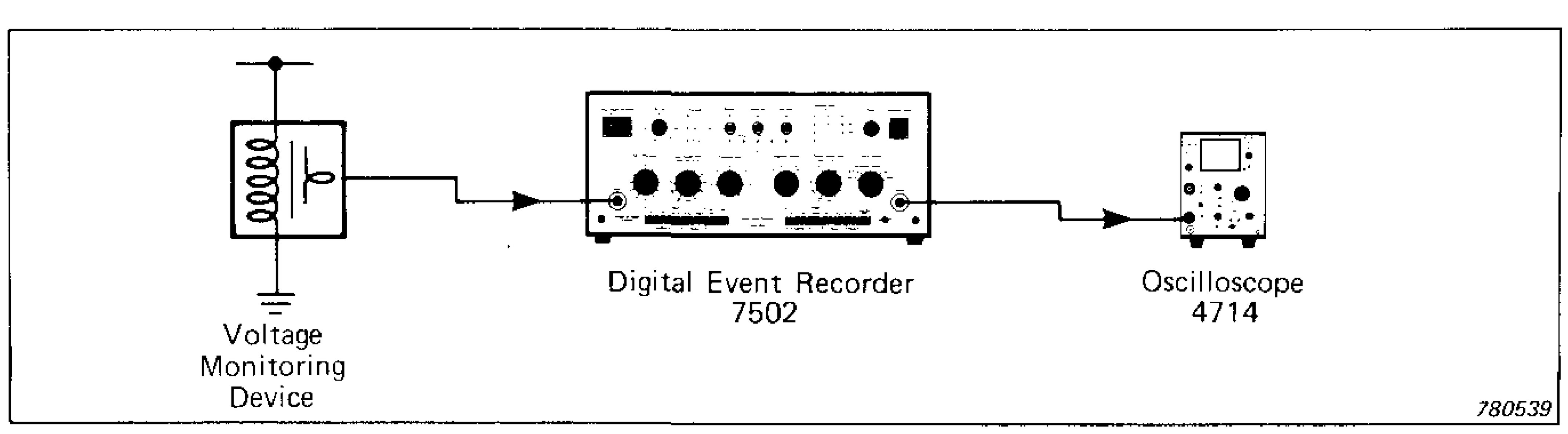


Illustration showing the use of a tape-loop cassette with the Type 7003 Tape Recorder

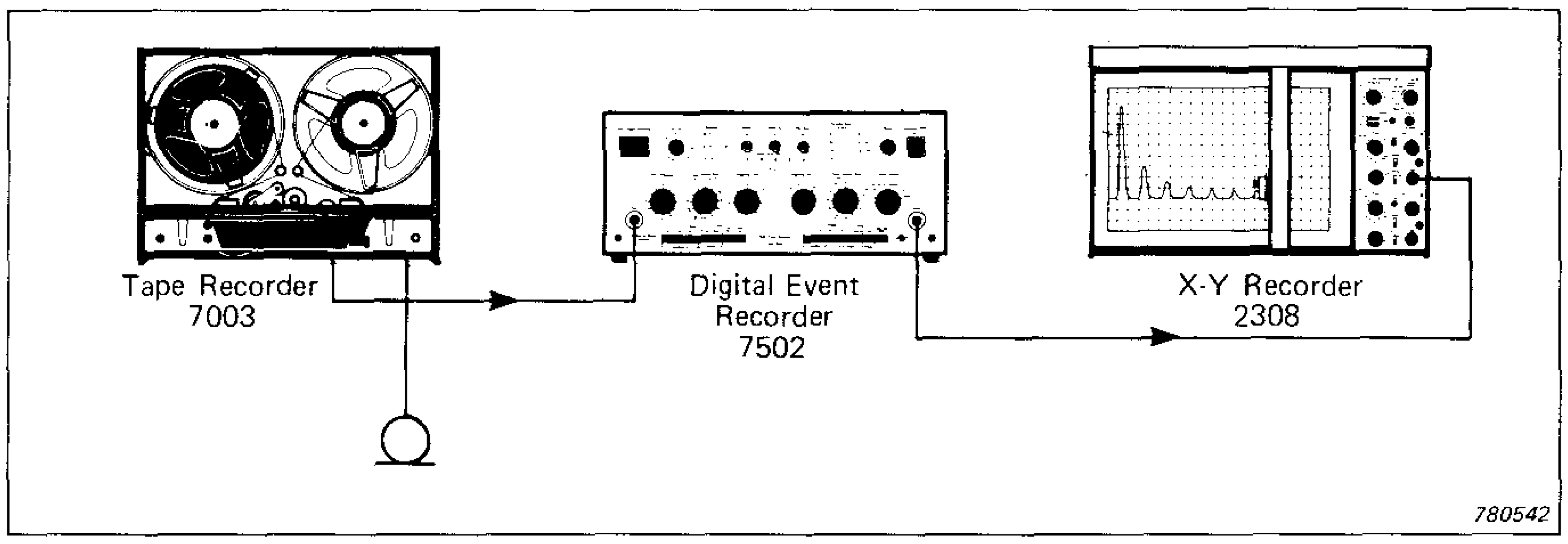
A tape loop cassette is included with the B & K Type 7003 tape recorder. It holds 0,85 to 2,5 m of tape, giving 2,23 to 6,56 sec of storage at 15 i.p.s. tape speed. Any of the channels of the Type 7003 may be converted from FM to Direct recording and reproduction, by means of plug-in cards ZE 0189 and ZE 0190, giving a frequency response of 100 Hz to 50 kHz (± 3 dB). Because of its independence of mains, the 7003 may also be used in this way on trials or even in service, for recording unpredictable fault conditions, power line disturbances and inrush waveforms.

For some applications it is helpful to have a recording-loop with more control over the record length and record/replay speed ratio than is possible with the tape cassette. Brüel & Kjær manufacture for this purpose a Digital Event Recorder, Type 7502. This is an all-solid-state device which nevertheless behaves like a tape loop with a wide range of record and playback rates and record lengths. Incoming analogue signals are converted into 8-bit digital words and stored in a 2048-word digital store (up to 5 such stores may be incorporated in the same cabinet, and any number of additional 7502's slaved together for extra channels, extra record length or extra dynamic range). The stored signal may subsequently be played back through a digital-to-analogue converter, at the same rate or a different rate, as many times as required. Like a tape loop, the store can continuously update.

Because it has no moving parts, the 7502 can be left running unattended indefinitely for recording and capturing very rare events. For example, a major aspect of the design of thyristor converters of all kinds for traction duties is the rating of the voltage-surge withstand, but especially on DC systems. These surges are generally developed across the supply inductance during current shedding by other trains, though on overhead collection systems they can also arise through lightning strikes. They are a characteristic of the particular wayside supply system, and have to be predicted reliably to ensure adequate design of the thyristor circuit. One way to obtain detailed information about surges is to connect a Type 7502 to a suitable voltage-monitoring device coupled to the supply. If the trigger level of the 7502 is adjusted to some appropriate multiple of the nominal maximum supply voltage, the first voltage surge to exceed that multiple will be recorded and stored for subsequent measurement. However, the integrity of the mains supply to the 7502 must be assured, so if it were used on a



Arrangement of equipment for capturing and measuring line voltage surges



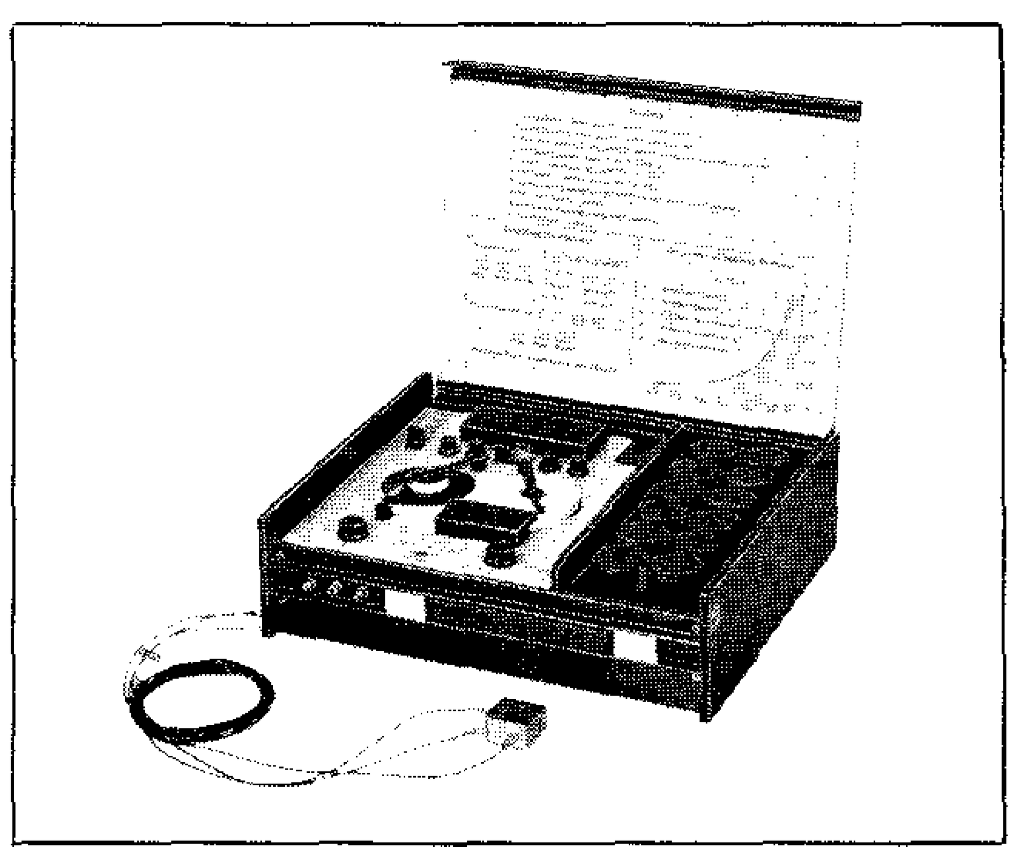
Arrangement of equipment for plotting inrush waveforms

train to capture the conditions leading up to, say, unforeseen failure of a string of thyristors, a separate battery and inverter would be needed (the basic 7502 consumes 85 W approx.).

Although the 7502 is the right instrument to use for recording and reproducing single surges, enabling the waveform leading up to the surge to be studied in detail, it is very useful to be able to gather data about the amplitude and duration of all the surges which occur on a traction supply over a prolonged period, i.e. at least one working day. In this case what the design engineer needs to know is the peak voltage and energy in any surge which can occur, so that the train-borne circuit can be equipped with filters which will either absorb or ride through the surges safely, without carrying around more weight of chokes and capacitors than are really necessary. An instrument which can be readily drafted into this duty, despite its unlikely name, is the B & K Type 2503 Bump Recorder.

The main purpose of the 2503 is to travel inside a shipping consignment recording any bumps which exceed a preset level, as well as the time of day, the date, the amplitude and the bump velocity. All this data is printed on a roll of paper, alphanumerically, and the instrument can go on working for days on end (its batteries will power it for 18 days). At the end of the journey the consignee who finds his shipment is damaged can identify when it was bumped and consequently decide who to claim against.

The bumps are converted to electrical signals by a built-in three-axis accelerometer, but because access is provided to the accelerometer connections, the 2503 may be connected to an external transducer of any kind, or an external electrical circuit, for recording and reducing data on any kind of transient or surge, provided the user takes care to ensure correct electrical matching. This is normally a matter of connecting a 1 nF capacitor in series with the lead to one only of the three inputs, and (for line voltage surge recording) providing a suitable voltage transformer with an output of about 10 mV to 1 V.


Type 2503 Bump Recorder

The Bump Recorder should then be calibrated by applying a known voltage and adjusting this to get a print-out. The data printed by the Recorder consists of peak acceleration and peak velocity, for which the electrical analogues are peak voltage and voltage time integral. Since the print-out is in SI units, the duration of each surge recorded can be obtained directly by dividing the velocity value by the acceleration value. The sensitivity of the 2503 to surges of less than 1 ms duration is reduced, but in general such fast transients are easy to filter out on a traction supply. It is the slower ones which cause the problems.

The versatile 2031 Narrow Band Analyzer can also act as a storage oscilloscope with a real-time display. It can store one previous event for comparative purposes. Furthermore, its large display screen enables accurate measurements to be taken of the shape of parts of the waveform, such as the rate of change of current in the commutation circuit of a chopper, for example.

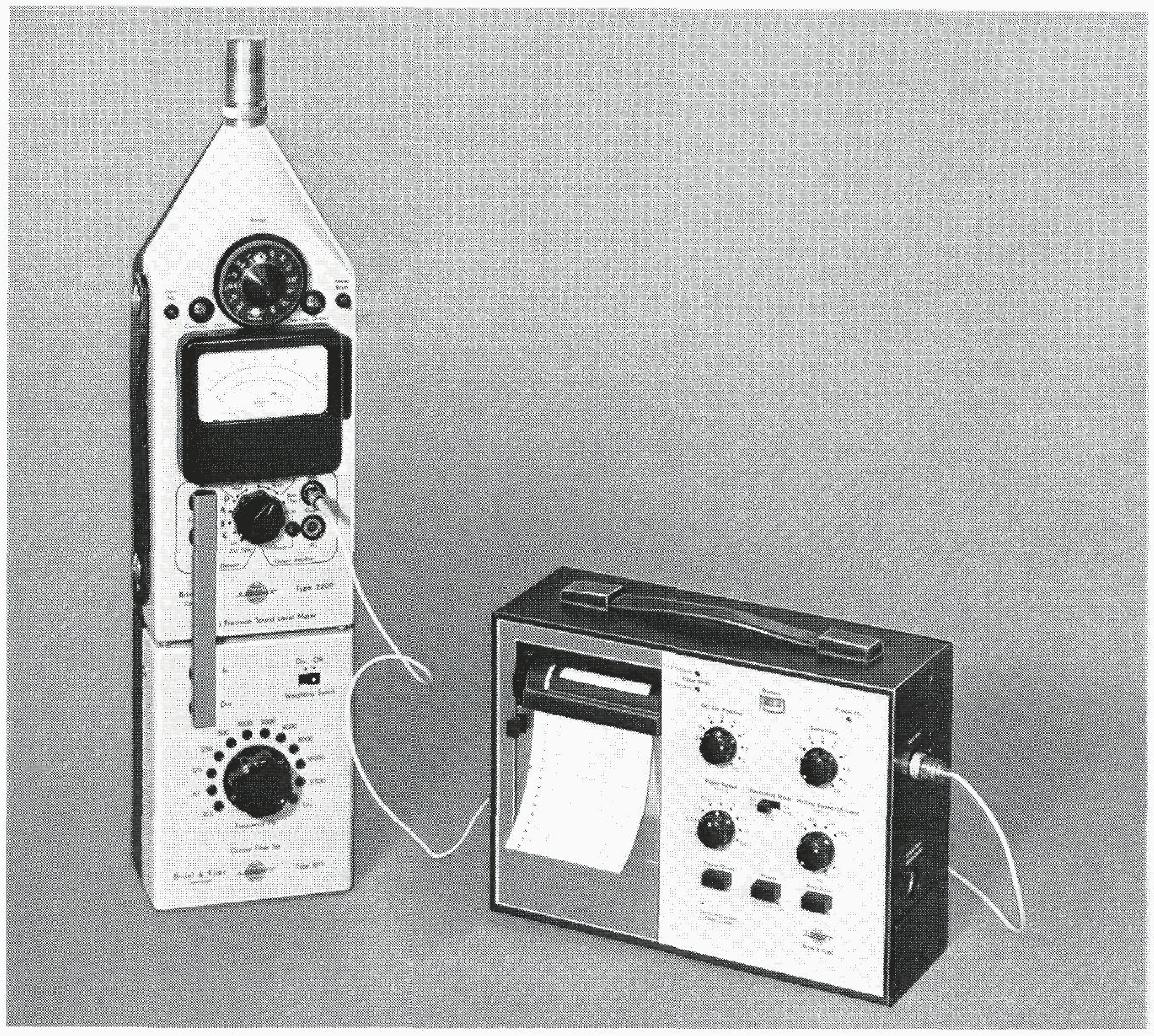
Because, as described above, chopper circuitry is full of fast-rising edges involving changes of hundreds of amps, a DC chopper can be a very powerful generator of acoustic noise. This is a peripheral phenomenon, often overlooked at the design stage, and because the noise is generated at harmonics of the chopping frequency, it is largely a matter of chance resonances whether the level is likely to be sufficient to cause annoyance when the equipment is installed in a train.

Many of the components used in a thyristor circuit can act as acoustic transducers, but the worst offenders are the chokes used to control the rate at which current increases and decreases in thyristors and diodes. These small chokes carry heavy currents and are always wound on a magnetic core. In many particulars, the most suitable material for this core is transformer steel, but it is very hard to stop steel laminations from vibrating in sympathy with the flux. For many applications it is possible to substitute cores which are no worse electrically but which generate far less acoustic noise.

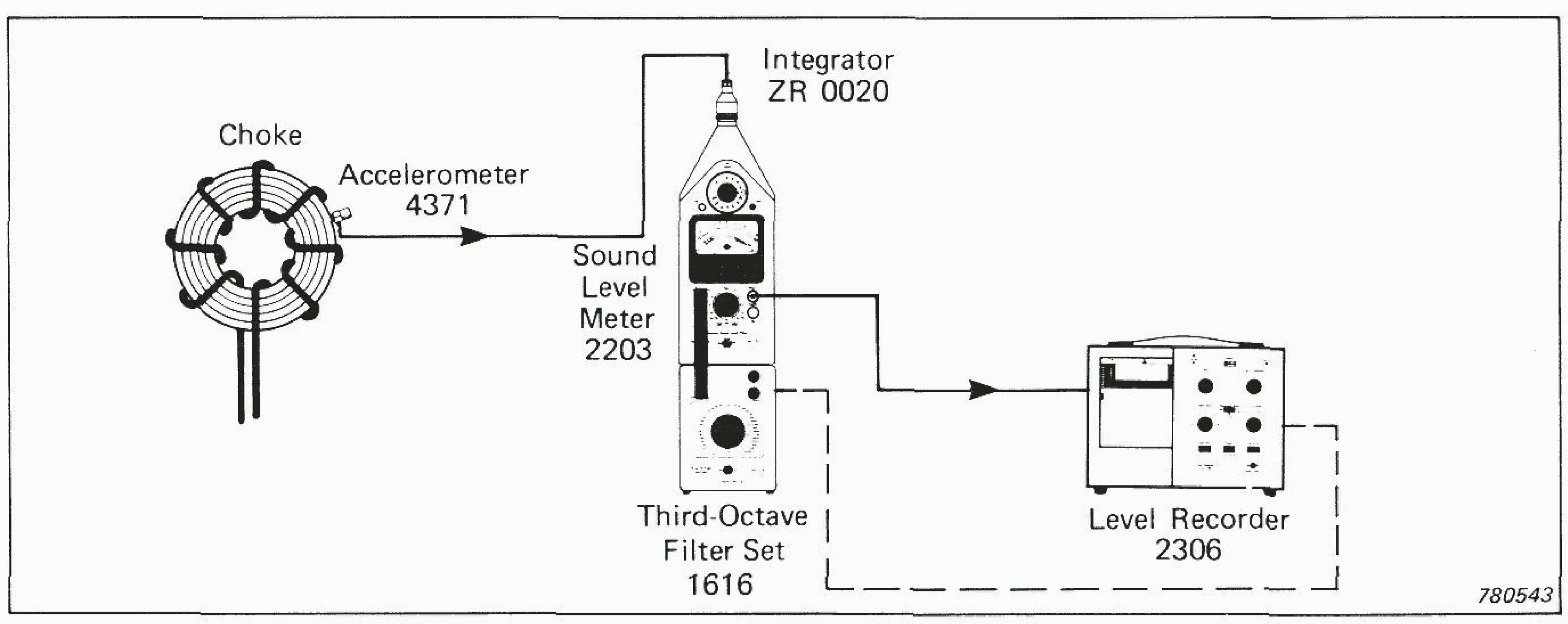
To measure the noise emitted by a DC chopper, a sound level meter should be used. Quite useful analysis of the harmonic content (which is often a function of the chopper case resonances rather than the chopper on-time) can be made with octave and third-octave filters in the meter circuit. Although an octave filter-range is not suitable for separating higher harmonics, its logarithmic frequency scale can give quite useful information about structure-dominated resonant behaviour. A sound level meter coupled to a tape recorder or graphic recorder should be used when experimenting with different choke cores to minimise acoustic noise.

Brüel & Kjær manufacture seven sound level-meters. The most suitable Types are 2203, 2209, 2210 or or 2218, plus a Type 1613 octave filter, or Type 2215 (which includes an octave filter). All these meters include A-weighting networks to take account of the sensitivity characteristics of the human ear.

Each sound level meter incorporates a precision condenser microphone acoustically mounted on top of the case; a preamplifier; a measuring amplifier (with attenuator and moving-coil meter); and an output for a recorder. All work off batteries and may be held in the hand, even with Type 1613 attached.



Type 2209 Sound Level Meter, attached to Type 1613 Octave Filter, and connected to Type 2306 Level Recorder



Arrangement of equipment to measure the vibration spectrum of iron-cored thyristor current-control choke in a DC chopper

Measuring the vibration modes of the magnetic cores which generate most of the sound is not as difficult as it might appear, particularly if a sound level meter is already available. All that is needed then is an accelerometer.

Brüel & Kjær accelerometers are all precision measuring-transducers using the piezoelectric effect to generate electrical analogues of the vibration to which they are subjected. A wide range is available for many kinds of application, but most are very small — less then an inch across and an ounce or so in weight.

In the chopper application the accelerometer would be attached by a magnet or wax to different parts of the choke core, in different orientations, and the output connected via the cable provided, and an integrator Type ZR 0020 (to measure displacement or velocity) to the microphone socket of the sound level meter. The latter could then be used to measure the level of vibration, and its AC output fed to an oscilloscope to observe the waveform, or to an analyzer, to determine the spectrum. The orientation of the accelerometer can also indicate the direction of the vibration, which ought to enable a distinction to be made between magnetostrictive and eddy-current induced forces.

For vibration and sound measurements Brüel & Kjær make a wide range of conditioning and analyzing instruments and equipment besides the items mentioned. For further information on these or any other instruments in the B & K range, contact your local agent.

The thyristor locomotive recordings used in the preparation of this note were generously provided by GEC Traction Ltd

Printed in U.S.A.

B&K Instruments, Inc.
Bruel & Kjaer Precision Instruments
5111 W. 164th Street, Cleveland, OH 44142 / Phone: (216) 267-4800