TYPE CLT1

COMPONENT LINEARITY TEST EQUIPMENT

RADIOMETER

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GENERAL

The Component Linearity Test Equipment, type CLT1, is developed and manufactured by Radiometer A/S. It is an advanced development of the Distortion Measuring Equipment, type ZTP 1271, which originally was developed and manufactured by Telefonaktiebolaget L. M. Ericsson, Sweden, patentees of the measuring method.
The equipment is intended for reliability investigations[1]) on electronic components and gives information of the same nature as obtained by the widely accepted current noise test on resistors. As the new measuring method offers a very high operational speed, is insensitive to external fields, and gives a high resolution, it is suited for automatic 100 % 'go/no go' production tests as well as for reliability investigations on a laboratory basis.

SPECIAL FEATURES

- *Wide impedance range of components from less than 1 Ω to above 100 MΩ.*
- *3rd harmonics as much as 150 dB below the fundamental can be measured.*
- *3rd harmonic indication either linear or logarithmic.*
- *Instantaneous and stable reading of 3rd harmonic voltage.*
- *Remote On–Off control as well as level control of fundamental possible.*
- *Max. test speed is 10 components per second.*
- *No sensitivity to hum and external fields.*

APPLICATIONS

- Investigations of the non-linearity of nominally linear electronic components with special reference to an evaluation of the component reliability.

  Component development
  Production testing
  Acceptance testing

- Investigations of non-linear components and materials.

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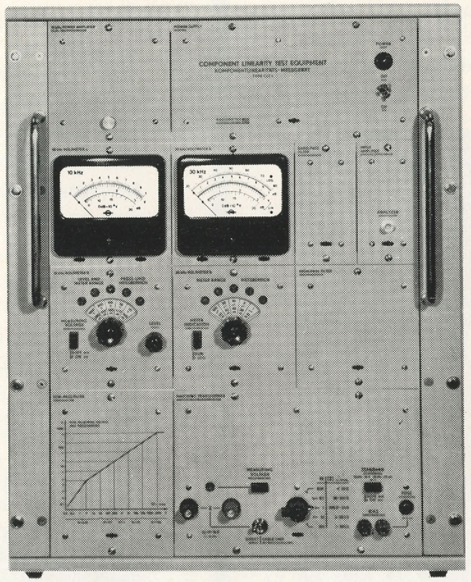

INTRODUCTION TO NON-LINEARITY MEASUREMENTS

Of late years it has become a very important problem to procure sufficiently reliable electronic components for very demanding applications, and efforts are being made to increase the reliability. Systematical reliability investigations are, however, a necessity for an evaluation of the improvements, and such are often made as environmental tests. This implies that a great number of components are to be subjected to external influence in order to determine their useful life. Unfortunately this procedure suffers from several disadvantages: It is time-consuming and may destroy the components. Furthermore, the accelerated environmental tests do not give a perfect picture of the components' behaviour under normal working conditions. For a running production test or incoming inspection, the environmental tests are out of the question.
What is needed is a fast, simple and non-destructive test method which will give information on the reliability of the components. This is fulfilled by the Component Linearity Test Equipment, type CLT1. The measuring method is based on a determination of the non-linearity of nominally linear electronic components, such as resistors and capacitors, the non-linearity being taken as a measure of their reliability. Experience has shown that those components of a batch which exhibit a relatively high non-linearity are less stable and probably have a shorter lifetime that the rest of the batch.
The non-linearity is determined by a selective measurement of the 3rd harmonic voltage generated in the component when a pure sinusoidal current is applied to it, the non-linearity being defined as the ratio between the 3rd harmonic voltage and the applied fundamental voltage, expressed in dB. As this measure depends on the applied fundamental voltage, it is common practice in the case of resistors to make the measurements at a power level of 1/4 W.
To overcome the problem of the dependence of the 3rd harmonic voltage on the fundamental voltage, the term Third Harmonic Index[2]), THI, has been defined as

$$\mathrm{THI} = 20 \log \frac{V_3}{V_1^3}$$

where the 3rd harmonic voltage, V_3, is measured in microvolts and the fundamental voltage, V_1, in volts.
For many component types, such as cracked carbon film resistors, the 3rd harmonic voltage, V_3, is proportional to the 3rd power of the applied fundamental voltage, V_1. As the THI turns out to be practically independent of the amplitude of the applied fundamental

voltage, V_1, the THI can be regarded as a parameter complimentary to the noise index with which the THI has a significant correlation. See Fig. 1.

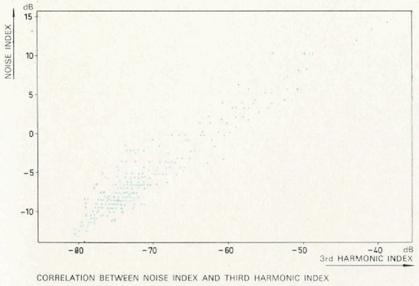

Figure 1. Correlation between noise index and 3rd harmonic index.
(By courtesy of Welwyn Electric Ltd.)

As previously mentioned, the non-linearity, alternatively the THI, is taken as a measure of the reliability of the components. The criterion for classifying a component as less reliable is that its non-linearity shall be substantially higher than the median non-linearity of the batch. If the latter is not known, a sample lot is measured. The results are plotted on probability paper, as shown in Fig. 2. The X-axis indicates the non-linearity, represented by the 3rd harmonic voltage V_3, and the Y-axis indicates the cumulative distribution of the components. On the probability paper chosen, a straight line corresponds to a pure Gaussian distribution, i.e. an ideal batch. The bend of the curve indicates an irregularity in the batch, and the questionable components are to be found in the region above the knee.

A rejection limit at $V_3 = 10 \times V_{3\,median}$ may be used for the whole batch, $V_{3\,median}$ corresponding to a cumulative distribution of 50 %. In the example shown, a slight screening of approx. 2 % is achieved.

For severe requirements, the rejection limit could be set as the 3rd harmonic voltage corresponding to the intersection between the $+2\sigma$ line and the idealized distribution curve that appears by an extension of the straight portion of the distribution curve. This is illustrated by the dotted line of Fig. 2. The screening now corresponds to approx. 10 %.

In production testing, it is normal to use as the rejection limit a fixed 3rd harmonic voltage corresponding to a non-linearity within the range −80 to −120 dB.

Rejection of the dubious components will in the first place improve the total reliability of the batch, but as long as high reliability rather is a question of even better production technique, the rejected components will enable the manufacturer to study the causes of failure. Knowledge of the nature of the failure will often make it possible to improve the production technique, and thus lead to a higher reliability.

COMPONENT DEFECTS

Below are stated some typical defects of resistors and capacitors which cause

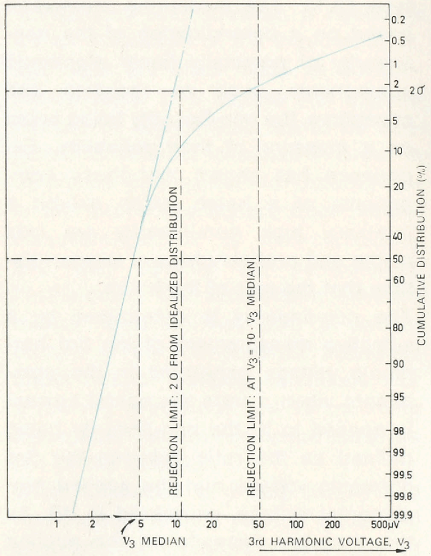

Figure 2. Determination of rejection limits.

non-linearity and which therefore can be detected by non-linearity measurements.

Resistors: (carbon, metal, or oxide film)

Contact Instability:

Poor contact between lead and cap
Poor contact between cap and film

Poor Quality of Film:

Inhomogeneous spots in film

Inferior Spiralling:

Traces of film left in grooves

Inferior Ceramic:

Longitudinal grooves in ceramic

Fig. 3 shows an enlargement of a defective resistor detected by having a 3rd harmonic voltage about 30 dB higher than the median value of a sample lot comprising 500 resistors.

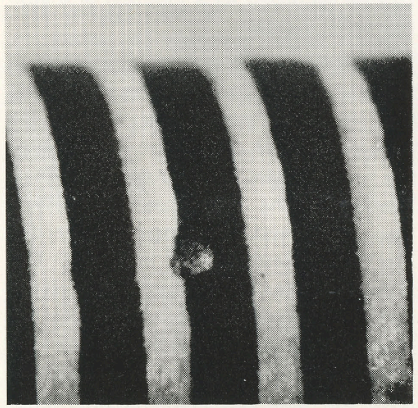

Figure 3. Defective resistor detected by having high non-linearity. A hole in the carbon film constricts the resistance path which results in excessive non-linearity because of overstraining of the carbon film.

Capacitors:

Contact Instability:

Poor contact between electrode and terminal

Contamination of Dielectric:

Iron oxide or even iron particles in mica, paper, polystyrene, etc.

Mechanical Instability:

Movements due to electrostatic forces

Fig. 4 shows an enlargement of a ceramic capacitor with a defective surface. This capacitor, which exhibits capacitive jumps of 50 ppm, was detected by unstable reading rather than by excessive non-linearity.

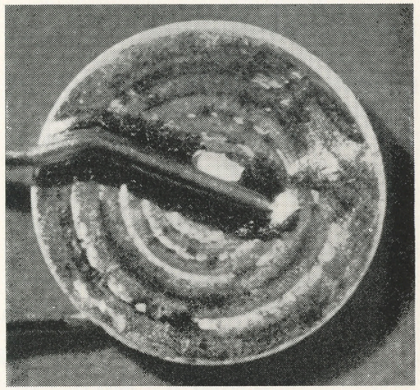

Figure 4. Defective ceramic capacitor detected by a very unstable 3rd harmonic voltage reading. The tinned surface has annular irregularities and a big hole at the terminal.

DESCRIPTION

A simplified block diagram of the working principle is shown in Fig. 5. A very pure sinusoidal current with the frequency 10 kHz is fed to the component under test, and the non-linearity is determined by a selective measurement of the 3rd harmonic voltage formed in the component.

Fig. 6 shows an equivalence diagram. The 3rd harmonic voltage, $e_{30\,kHz}$, generated in the component under test, is divided between the impedance, $Z_{30\,kHz}$, of the component and the input im-

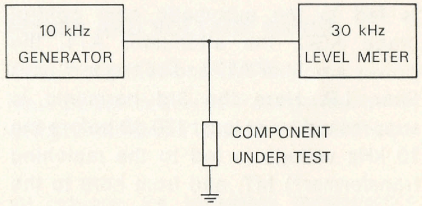

Figure 5. Simplified block diagram.

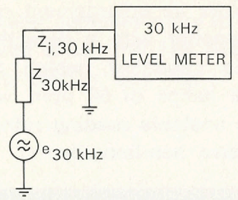

Figure 6. Equivalence diagram.

pedance, $Z_{i,\ 30\ kHz}$, of the selective 30 kHz voltmeter, the loading caused by the 10 kHz generator being negligible at 30 kHz. As the impedance $Z_{30\ kHz}$ increases, the effective voltage yield at the input of the 30 kHz voltmeter decreases, which seriously would affect the sensitivity unless precautionary measures were taken. By introducing a special low-distortion matching transformer, the component under test can be matched to the generator and the 30 kHz voltmeter within a wide component range. By multiplying the 3rd harmonic reading by a correction factor F_c, the output voltage, $e_{30\ kHz}$, of the "3rd harmonic generator" of the component under test is obtained. See specifications for definitions of F_c.

The **R**esidual **N**on-**L**inearity RNL of the instrument is rather important as it sets the limit as to the measuring performance. See specifications for definition of RNL. In order to compare the residual non-linearity, RNL, with the non-linearity of the component under test, it is necessary to use the **C**orrected **R**esidual **N**on-**L**inearity, CRNL, which is derived from the RNL by means of the correction factor F_c. See specifications.

Fig. 7 shows a detailed block diagram. The output from the 10 kHz oscillator is fed to the automatic gain control stage AGC, the attenuator AT1, the power amplifier A1, and to the low-pass filter, LP. Here the 3rd harmonic is suppressed by at least 170 dB before the 10 kHz voltage is fed to the matching transformer*) MT, and from here to the component under test. The 10 kHz voltage is measured by means of the voltmeter consisting of the attenuator AT2, the amplifier A2, and the meter M1. The automatic amplitude control stage, AAC, is connected to the voltmeter and controls the AGC stage in order to keep the 10 kHz voltage constant and independent of variations in loading. As the attenuators AT1 and AT2 are mechanically connected, the sensitivity of the voltmeter is automatically set in accordance with the selected voltage range of the generator. Adjustment of the 10 kHz voltage within the range selected is accomplished by adjusting the AAC stage, but external control can be introduced by applying a dc voltage to the AAC stage. By applying a sliding dc voltage, the 3rd harmonic voltage can be recorded as a function of a sliding fundamental.

The 3rd harmonic voltage developed in the component under test is passed via the matching transformer MT to the high-pass filter HP which suppresses the fundamental in order to avoid overloading of the subsequent amplifiers. The 3rd harmonic voltage is then fed via the preamplifier A3 to the 30 kHz bandpass-filter, BP, which also determines the noise bandwidth. Then the filtered voltage is fed to the 30 kHz voltmeter which consists of the attenuator AT3, the amplifier A4, and the meter M2. Linear meter indication is normal, but logarithmic indication over a 60 dB range is also possible.

The voltmeter has a recorder output to which a limit sensor giving a 'go/no go' signal can be connected, if the equipment is to be used for automatic production testing. The 10 kHz generator is provided with a control input for remote switching of the 10 kHz voltage from an external switch. The low response time of the test equipment makes it possible to test up to 10 components per second.

*) Patents pending

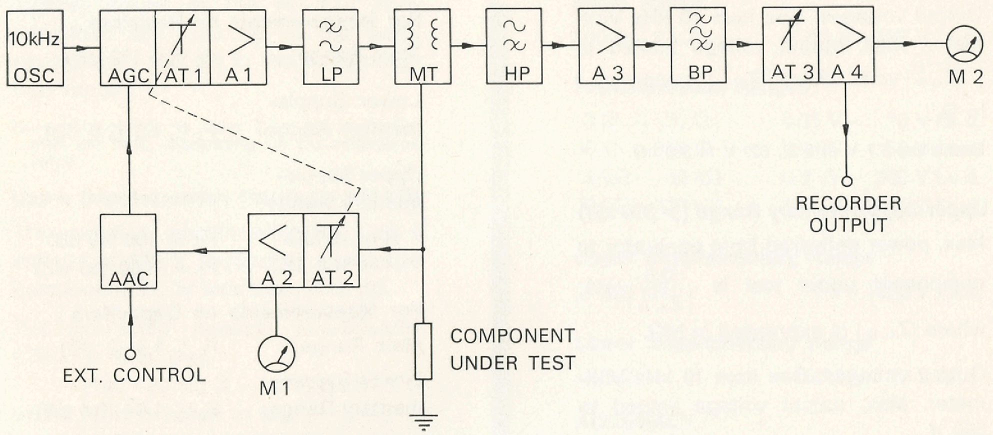

Figure 7. Detailed block diagram.

Dynamic measurements may be made by sweeping the fundamental, the external control voltage being the sawtooth voltage from an oscilloscope. By connecting the recorder output voltage to the oscilloscope, the non-linearity as a function of the fundamental voltage can be conveniently viewed on the oscilloscope, especially if the logarithmic indication mode is used.

TENTATIVE SPECIFICATIONS

COMPONENT RANGE

Fundamentally the component range comprises all passive impedances. The equipment is primarily adapted to impedances of magnitudes within the main range. Measurements within the supplementary ranges are encumbered with certain restrictions, which appears from the specifications.

The individual ranges are selected by means of the N-switch of the Matching Transformer and indicated in ohms corresponding to the magnitude of the component's impedance at 10 kHz, $|Z_{x,\ 10}|$.

A. MAIN RANGE

Basic Range

300 Ω – 3 kΩ	N* = 1

Transformation Ranges

3 Ω – 30 Ω	N = 0.01
30 Ω – 300 Ω	N = 0.1
3 kΩ – 30 kΩ	N = 10
30 kΩ – 300 kΩ	N = 100

B. SUPPLEMENTARY RANGES

Upper Supplementary Range

> 300 kΩ	N = 100

Lower Supplementary Range

< 3 Ω	N = 0.01

GENERATOR FREQUENCY

10 kHz (Fundamental)

MEASURING FREQUENCY

30 kHz (3rd harmonic)

POWER AND VOLTAGE RANGE

Main Range (3 Ω – 300 kΩ)

Max. power delivered from generator to component under test is 1 VA.

*N indicates the impedance transformation ratio of the built-in matching transformer

Output voltages: See item 10 kHz Voltmeter. Max. output voltage limited to $\sqrt{|Z_{x,10}|}$ volts, where $|Z_{x,10}|$ is expressed in Ω.

Examples: 1.7 V at 3 Ω, 550 V at 300 kΩ.

Upper Supplementary Range (> 300 kΩ)

Max. power delivered from generator to component under test is $\frac{0.3}{|Z_{x,10}|}$ VA, where $|Z_{x,10}|$ is expressed in MΩ.

Output voltages: See item 10 kHz Voltmeter. Max. output voltage limited to 550 V.

Lower Supplementary Range (< 3 Ω)

Max. power delivered from generator to component under test is $0.33 \times |Z_{x,10}|$ VA, where $|Z_{x,10}|$ is expressed in Ω. Output voltages: See item 10 kHz Voltmeter. Max. output voltage limited to $0.58 \times |Z_{x,10}|$ volts, where $|Z_{x,10}|$ is expressed in Ω.

GENERATOR OUTPUT IMPEDANCE

Less than N × 5 Ω.

INPUT IMPEDANCE OF 30 kHz VOLTMETER

Magnitude: N × 1 kΩ ± 2 %

Phase Angle: $|\Theta| < 5°$

CORRECTION FACTOR

The correction factor is defined as

$$F_c = \left| \frac{Z_{x,30}}{N} + 1 \right|,$$

where $Z_{x,30}$ indicates the component's impedance at 30 kHz in kΩ.
By multiplying the 3rd harmonic reading by the correction factor, the open-circuit value of the 3rd harmonic voltage produced by the component is obtained. Typical values are stated below.

For Measurements on Resistors

Main Range:	$F_c \leq 4$ (12 dB)
Lower Supplementary Range:	$F_c \leq 1.3$ (2.3 dB)
Upper Supplementary Range:	
R = 10 MΩ	$F_c = 100$ (40 dB)
R = 100 MΩ	$F_c = 1000$ (60 dB)

For Measurements on Capacitors

Main Range:	$F_c \leq 1.4$ (3 dB)
Lower Supplementary Range:	$F_c \leq 1.04$ (0.4 dB)

For Measurements on Inductors

Main Range:	$F_c \leq 9$ (19 dB)
Lower Supplementary Range:	$F_c \leq 1.4$ (3 dB)

RESIDUAL NON-LINEARITY

The residual non-linearity RNL is defined as RNL =

$$20 \log \frac{\text{residual 3rd harm.} + \text{noise}}{\text{fundamental}} \text{ dB.}$$

The corrected residual non-linearity CRNL, which is the RNL referred to the "3rd harmonic generator" of the component under test, is defined as CRNL =

$$20 \log \frac{\text{residual 3rd harm.} + \text{noise}}{\text{fundamental}} F_c \text{ dB}$$

where F_c is the correction factor.

Note: The "residual 3rd harm. + noise" is the reading of the 30 kHz voltmeter when the component under test is replaced by a virtually linear component of the same impedance.

Noise comprises the thermal noise of the component and the noise of the instrument proper.

Measuring error originating in the RNL is max. 10 % for a non-linearity of the component being 20 dB above the CRNL.

Main Range

The residual non-linearity RNL for 0.25 VA delivered to a resistive component is less than –150 dB in the basic range (N = 1), and less than –140 dB in the transformation ranges (N = 0.01, 0.1, 10, and 100).

Typical values of the residual non-linearities are –160 dB in the basic range, and –150 dB in the transformation ranges.

Note: The CRNL is from 2 to 12 dB higher than the RNL, depending on the resistance value.

Upper Supplementary Range (> 300 kΩ)

The residual non-linearity RNL at a voltage of 275 V applied to a resistive component, R_x, is less than –140 dB.

The corrected residual non-linearity CRNL is less than

$$-[140 - 20 \log (1 + 10 R_x)] \text{ dB}$$

where R_x is inserted in MΩ.

Note: 275 V correspond to 0.25 VA dissipated in 300 kΩ. In the MΩ range it is more reasonable to use the CRNL for a valuation of the measuring performance since the correction factor F_c may be very large.

Examples:
R_x = 10 MΩ: CRNL < —100 dB
R_x = 100 MΩ: CRNL < — 80 dB

Lower Supplementary Range (< 3 Ω)

The residual non-linearity RNL at a voltage of $0.29 \times R_x$ V applied to a resistive component, R_x, is less than:

$$-\left[140 + 20 \log \frac{R_x}{3}\right] \text{ dB}$$

where R_x is inserted in Ω.

Note: 0.29 A corresponds to 0.25 VA dissipated in 3 Ω. The CRNL is from 0 to 2 dB higher than the RNL, depending on the resistance value.

Example:
R_x = 0.3 Ω: CRNL ~ RNL < —120 dB.

10 kHz VOLTMETER

The equipment has a common range switch for the generator amplitude and the 10 kHz voltmeter sensitivity. Therefore, the voltage range indicated is valid for both the generator and the voltmeter. A fine control sets the 10 kHz voltage within the range selected. The range index is automatically switched in accordance with the selected component range.

Note: The range switch has 7 positions in a 1—3—10 sequence. Max. generator output voltage is 550 V.

Basic Range

300 Ω – 3 kΩ	0.1 V – 100 V f.s.d.

Transformation Ranges

3 Ω – 30 Ω	0.01 V – 10 V f.s.d.
30 Ω – 300 Ω	0.03 V – 30 V f.s.d.
3 kΩ – 30 kΩ	0.3 V – 300 V f.s.d.
30 kΩ – 300 kΩ	1 V – 1000 V f.s.d.

Upper Supplementary Range

> 300 kΩ	1 V – 1000 V f.s.d.

Lower Supplementary Range

< 3 Ω	0.01 V – 10 V f.s.d.

ACCURACY

2 % of reading + 1 % of full scale.

METER SCALES

Two linear voltage scales 0 to 1 and 0 to 3. One dB scale –2 to 20 dB. The total dB range, by utilizing the range switch, is 82 dB. dB calibration referred to 10^{-8} V.

30 kHz VOLTMETER

The meter has a linear and a logarithmic indication mode. The range index is automatically switched in accordance with the selected component range. The sensitivities are given without regard to the correction factor.

Note: The range switch has 11 positions in a 1—3—10 sequence.

A. LINEAR INDICATION

Basic Range

300 Ω – 3 kΩ	1 µV – 100 mV f.s.d.

Transformation Range

3 Ω – 30 Ω	0.1 µV – 10 mV f.s.d.
30 Ω – 300 Ω	0.3 µV – 30 mV f.s.d.
3 kΩ – 30 kΩ	3 µV – 300 mV f.s.d.
30 kΩ – 300 kΩ	10 µV – 1 V f.s.d.

Upper Supplementary Range

> 300 kΩ	10 µV – 1 V f.s.d.

Lower Supplementary Range

< 3 Ω	0.1 µV – 10 mV f.s.d.

ACCURACY

Basic Range (300 Ω – 3 kΩ)

3 % of reading + 1 % of full scale.

Transformation and Supplem. Ranges

5 % of reading + 1 % of full scale.

METER SCALES

Two linear voltage scales 0 to 1 and 0 to 3. One dB scale –2 to 20 dB. The total dB range, by utilizing the range switch, is 122 dB. dB calibration referred to 10^{-8} V.

B. LOGARITHMIC INDICATION

Basic Range

300 Ω – 3 kΩ	40 – 140 dB above 10^{-8} V

Transformation Ranges

3 Ω – 30 Ω	20 – 120 dB above 10^{-8} V
30 Ω – 300 Ω	30 – 130 dB above 10^{-8} V
3 kΩ – 30 kΩ	50 – 150 dB above 10^{-8} V
30 kΩ – 300 kΩ	60 – 160 dB above 10^{-8} V

Upper Supplementary Range

> 300 kΩ	60 – 160 dB above 10^{-8} V

Lower Supplementary Range

< 3 Ω	20 – 120 dB above 10^{-8} V

ACCURACY

Basic Range

1 dB

Transf. and Supplementary Ranges

1.2 dB

METER SCALE

One linear dB scale 20 to 80 dB.

Note: The dB ranges specified above are inclusive of the 60 dB scale range of the meter, i.e. the range switch utilizes 5 positions only.

Example: Basic Range:
Range switch from 20 to 60 dB
Total dB range from 40 to 140 dB

MEASURING VOLTAGE CONTROL

A. Ext. On-Off Switch

A control input provides for remote switching of the 10 kHz voltage by means of an external make switch.

Note: An additional external make switch is required for the warning lamp next to the measuring terminals.

B. Ext. Voltage Control

A control input provides for external electronic control of the 10 kHz voltage by means of a dc control voltage. The 10 kHz voltage can be varied from 0 to 100 % of the value indicated by the range switch.

DC Control Voltage

1 V for 100 % of range indication. The 10 kHz voltage is proportional to the control voltage.

Input Resistance

Greater than 2 kΩ.

MEASURING SPEED

Up to 10 components per second.
See Fig. 8 for further information.

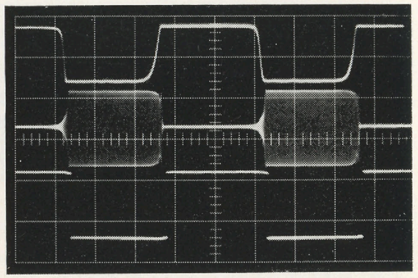

Figure 8. Oscillogram shows the 10 kHz voltage with appropriate recorder output voltage, controlled by a square-wave voltage. Horizontal scale is 20 ms/cm.

Upper trace: 10 Hz square-wave voltage used as control voltage. Vertical scale is 0.5 V/cm.

Middle trace: 10 kHz voltage at measuring terminals. Vertical scale is 10 V/cm.

Lower trace: Recorder output voltage at linear meter indication mode. Vertical scale is 0.5 V/cm.

DC BIAS

A bias input provides for dc bias of the component under test. It cannot be used in the transformation ranges 3 Ω – 30 Ω, and 30 Ω – 300 Ω, or in the lower supplementary range, < 3 Ω.

Max. dc Voltage

200 V.

Max. dc Current

30 mA.

OUTPUTS

A. Analyzer Output

For investigations of harmonics of a higher order than the 3rd. Requires that the instrument is set for the basic range where no matching transformer is employed.

B. Recorder Output

For registration of the 3rd harmonic at both linear and logarithmic indication. Loading of the recorder output does not affect the meter reading.

Output Voltage

1 V dc for full-scale deflection on meter.

Output Resistance

4 kΩ.

TERMINALS AND CONNECTORS

A. Measuring Terminals

Two binding posts. Accept component clips with standard-size banana plugs (4 mm).

B. DC Bias

Two binding posts. Accept standard-size banana plugs (4 mm).

C. Analyzer Output

BNC type UG-290U coaxial socket.

D. 12-pole Connectors

Two 12-pole connectors – located on the rear and connected in parallel – are provided for:

Recorder Output
Measuring Voltage Control, i.e.
- Ext. On–Off Switch
- Ext. Warning Lamp Switch
- Ext. Voltage Control

POWER SUPPLY

Voltages: 110, 115, 127, 200, 220, 240 V
Line Frequencies: 45 to 60 Hz
Consumption: 22 VA

DIMENSIONS AND WEIGHT

Height:	630 mm (25")
Width:	500 mm (19¾")
Depth:	310 mm (12¼")
Weight:	40 kilos net (88 lbs net)

ACCESSORIES SUPPLIED

1 code 900-215 Cable Unit

Extension cable terminated by 2 measuring terminals. Makes possible measurements up to 90 cm (36 inches) away from the CLT1 (Cannot be used in the range N = 100).

2 code 805-015/805-022 12-pole plugs:
For connection of cables from external recorder and external control unit, if any.

1 type 12G19-1.5 power cord.

ACCESSORIES AVAILABLE

1 pair of Component Clips, code 807-200
For easy component insertion.

References

1. V. Peterson and P. O. Harris, "Harmonic testing pinpoints passive component flaws", Electronics, July 11, 1966, pp. 93—100.
2. P. L. Kirby, "The non-linearity of fixed resistors", Electronic Engineering, Nov. 1965, pp. 722—726.

Data subject to change without notice.

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