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Aerospace — Characteristics of aircraft electrical systems

Aéronautique — Caractéristiques des réseaux électriques à bord des aéronefs

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FOREWORD

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Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council.

International Standard ISO 1540 was developed by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, and was circulated to the member bodies in July 1976.

It has been approved by the member bodies of the following countries :

Australia	Germany	Spain
Austria	India	Turkey
Belgium	Ireland	United Kingdom
Brazil	Italy	U.S.A.
Canada	Mexico	U.S.S.R.
Czechoslovakia	Philippines	

The member body of the following country expressed disapproval of the document on technical grounds :

France

Aerospace — Characteristics of aircraft electrical systems

1 SCOPE AND FIELD OF APPLICATION

1.1 This International Standard specifies the characteristics of electrical power supplied to the terminals of airborne equipment and defines limits for those aspects of utilization equipment which may adversely affect the characteristics of electrical power supplied to other equipment.

Its purpose is to achieve compatibility between airborne utilization equipment and aircraft electrical power supplies. Ground support electrical power supplies will be the subject of a separate International Standard.[1)]

1.2 The characteristics specified in this International Standard are based on the following assumptions :

1) the system capacity is not less than 1,5 kW;

2) the normal loading on the system is between 5 % and 85 % of the power supply system capacity;

3) the load balance in a.c. systems is such that under steady-state conditions the maximum difference in line current on any power source does not exceed 15 % of the rated current of that power source; and

4) the power factor in a.c. systems is between 0,8 lag and 1,0 at loads between 30 % and 85 % of rated load, and between 0,5 lag and 1,0 at loads between 5 % and 30 % of rated load.

2 DEFINITIONS

2.1 electrical system (also called simply "system") : A combination of power sources and utilization equipment connected to a main distribution point.

NOTE — There may be more than one power source on each system and more than one system in an aicraft electrical installation.

2.2 power system capacity : The total nominal capacity of the power sources in a system under the prescribed operating and environmental conditions in the aircraft, due allowance being made for any reduction in available power in parallel operation.

2.3 main power source : A generator, usually driven by one of the aircraft propulsion engines, or a power conversion device (not forming part of utilization equipment) installed to provide electrical power during normal operation of the aircraft.

2.4 emergency power source : A generator, a power conversion device (not forming part of utilization equipment) or a battery, installed to provide electrical power for essential purposes during conditions of electrical emergency in flight.

2.5 normal system operation : The conditions which obtain when the electrical system performs the various intended operations during the aircraft operational period and when no fault occurs. Examples of such operations are switching of utilization equipments, engine speed changes, busbar switching and paralleling of power sources.

2.6 abnormal system operation : The condition that arises due to deterioration or loss of control of voltage and/or frequency, the magnitude and duration of the disturbance being limited by the protection circuits. This condition only occurs rarely and at random.

NOTE — In the event of a limited fault occurring, the system steady-state voltage could be anywhere within the abnormal steady-state limits (ASSL) since these define the limits for operation of the protective system. Such a fault is extremely rare and would only be revealed by a check of the system voltage, possibly requiring instruments of higher accuracy than those normally installed in the aircraft.

2.7 *emergency system operation* : The conditions that arise in flight when the main power sources are unable to provide sufficient or proper power, thus requiring use of the limited emergency power source(s).

2.8 steady-state conditions : Conditions that prevail at any fixed load when only inherent or natural changes occur, i.e. no fault occurs and no deliberate change is made to any part of the system.

1) In preparation.

2.9 utilization equipment : Any individual unit or any functional group of units to which, as a whole, electrical power is applied.

NOTE — In the interests of simplicity only values applicable to the majority of aircraft electrical equipment are specified in this International Standard. These are to be regarded as preferred values.

It is recognized, however, that for special applications equipment may be required to operate over narrower, or alternatively, wider voltage ranges. For such special applications appropriate minimum values of steady-state voltages and step-functions of voltage must be specified in the relevant aircraft/equipment specification.

2.10 earth (ground) : The primary aircraft structure is normally the referenced earth, the neutral of the a.c. and the negative of the d.c. in the power generation and power utilization systems.

2.11 a.c. phase voltage : The a.c. voltages stated herein shall be for any phase of those supplied to utilization equipment, a phase being considered the line-to-neutral (earth) circuit at the equipment terminals. The voltage values are r.m.s. values unless otherwise stated.

2.12 average r.m.s. value : The arithmetical sum of the individual r.m.s. values of phase voltages divided by the number of phases.

2.13 transient : The short term changing condition of a characteristic that goes beyond the steady-state limits and returns to the steady-state limits within a specified time period. For the purposes of this International Standard, voltage transients are divided into surges and spikes.

2.14 surge : A variation from the controlled steady-state voltage level of a characteristic resulting from the inherent regulation of the electrical power supply system and remedial action by the regulator.

2.15 spike : A variation from the surge level or from the controlled steady-state voltage level of a characteristic resulting from the switching of inductive loads. Such action usually generates a train of spikes, each of which attains high amplitude in an extremely short time.

2.16 total harmonic content : The total r.m.s. voltage or current remaining when the fundamental component of a complex wave-form is removed.

2.17 frequency modulation : The cyclic and/or random variation of frequency about a mean frequency during steady-state electrical system operation. It is normally within a narrow band of frequency and it is often non-sinusoidal.

2.18 frequency modulation repetition rate : The reciprocal of the period of the frequency modulation wave-form.

2.19 frequency drift : The slow and random variation of the controlled frequency level within the steady-state limits.

2.20 voltage modulation : The cyclic and/or random variation of the peak value of a.c. voltage about a mean value during steady-state electrical system operation caused, for example, by voltage regulation or speed variations. The voltage modulation envelope is formed by the continuous curve joining successive peaks of the basic voltage wave.

2.21 voltage modulation frequency components : The components at individual frequencies that together make up the voltage modulation envelope.

2.22 voltage ripple : The cyclic and/or random variation of the d.c. voltage about a mean level during steady-state electrical system operation.

2.23 equivalent step-function : A mathematical function that is used in this International Standard to provide a definitive basis for comparison of actual surges recorded on the electrical system with the requirements stated herein.

2.24 crest factor : The crest factor of an a.c. voltage wave-form is the ratio of the peak to r.m.s. values.

NOTE — The following abbreviations are used in this International Standard :

1) normal steady-state limits : NSSL

2) abnormal steady-state limits : ASSL

3) emergency steady-state limits : ESSL

3 GENERAL REQUIREMENTS

3.1 Power systems

3.1.1 *General*

Every power system shall be designed so that normal service maintenance will ensure the retention of the specified characteristics throughout the full range of operational and environmental conditions likely to be encountered in the aircraft in which it is installed. The electrical power sources shall be so designed and controlled as to ensure that the characteristics of electrical power at the utilization equipment terminals are in accordance with the requirements of this International Standard and shall be so installed and protected that the failure of any power source and its disconnection from the system does not result in subsequent impaired performance of the remaining power sources.

3.1.2 *A.C. power*

The a.c. power system shall be three-phase, four-wire, star-connected having a nominal voltage of 115/200 V, a nominal frequency of 400 Hz and a phase sequence A-B-C (see figure 1). The neutral point of each source of power shall normally be connected to earth (see 2.10), which shall then be considered the fourth wire. Where an auxiliary single-phase supply is provided, it shall meet the line-to-neutral requirements stated herein.

3.1.3 *D.C. power*

The d.c. power system shall be a two-wire system having a nominal voltage of 28 V. The negative of each power source shall normally be connected to earth, which shall then be considered the second wire.

3.2 Utilization equipment

3.2.1 Utilization equipment shall maintain the specified performance when supplied with power having the ranges of characteristics detailed herein and shall not degrade the power characteristics beyond their limits. When use is required of power having other characteristics or closer tolerances than are specified herein, the conversion to other characteristics or closer tolerances shall be accomplished as a part of the utilization equipment.

3.2.2 The individual specification for the utilization equipment shall state the degrees of degradation of performance, if any, permitted in specific regions of normal, abnormal and emergency system operations.

4 CONSTANT FREQUENCY A.C. POWER SYSTEM CHARACTERISTICS

NOTE — The characteristics below apply to the power at the utilization equipment terminals unless otherwise stated.

The voltage characteristics apply to line-to-neutral quantities; line-to-line characteristics should be as a result of the line-to-neutral values being as shown.

All a.c. voltage values are r.m.s. values unless otherwise stated.

Transient surge r.m.s. voltages are derived from the recorded peak values.

4.1 Steady-state characteristics

4.1.1 *Voltage*

The individual phase voltages and average of the three phase voltages shall be within the limits specified in table 3.

4.1.2 *Phase displacement*

The displacement between the corresponding zero points on the wave-form shall be within the limits 118 and 122°.

4.1.3 *Voltage unbalance*

The maximum difference between individual phase voltages shall not exceed 3 V in normal operation, and 4 V in emergency operation.

4.1.4 *Voltage wave-form* (see also annex A)

The voltage wave-form shall be such that all the following criteria are satisfied :

1) the crest factor lies between 1,31 and 1,51;

2) the r.m.s. value of the total harmonic content does not exceed 5 % of the fundamental r.m.s. voltage;

3) no individual harmonic exceeds 4 % of the fundamental voltage;

4) the divergence of corresponding ordinates from those of the equivalent sine wave does not exceed $(15,5 + 5,5 \cos 2\theta)$ % of the measured r.m.s. voltage, where $V_p \sin\theta$ is the equation of the equivalent sine wave.

4.1.5 *Voltage modulation*

The modulation of phase voltage (including the effects of frequency modulation) shall not exceed 3,5 V when measured as the peak-to-valley difference between the maximum and minimum peak voltages reached on the modulation envelope over a period of at least 1 s. Frequency components of the modulation envelope wave-form shall be within the limits shown in figure 2.

4.1.6 *Frequency*

The frequency of main power supplies shall be maintained within the normal limits 380 Hz and 420 Hz, or abnormal limits 370 Hz and 430 Hz, and that of emergency power supplies within 360 Hz and 440 Hz.

NOTES

1 It is acknowledged that many systems have steady-state frequency limits held to much closer tolerances. When these apply they should be stated in the relevant specifications.

2 Where use of the emergency system is required at frequencies below 360 Hz, the voltage shall be so controlled that it does not exceed the value given by $f/3$ where f is the frequency in hertz; for example at 300 Hz, the voltage shall not exceed 100 V.

4.1.7 *Frequency drift*

Variation of the controlled frequency due to drift shall not exceed ± 5 Hz and the rate of frequency drift shall not exceed 15 Hz/min.

4.1.8 *Frequency modulation*

Frequency variations due to modulation shall be such that the departure from the average frequency lies within the limits defined in figure 3.

4.2 Transient characteristics (see also annex B)

4.2.1 *Voltage*

4.2.1.1 GENERAL

Surge voltages, when converted to their equivalent step-functions (see 8.1), shall be within the limits of figure 4 for all operations of the aircraft system. The most severe phase transient shall be used in determining conformity with this requirement.

In addition to surge voltages the switching of equipments will produce spike voltages. The test to demonstrate the ability of equipment to withstand spike voltages is specified in annex B.

4.2.1.2 NORMAL SYSTEM OPERATION

4.2.1.2.1 Limits 5 and 6 of figure 4 apply when switching loads from 5 % up to 85 % and down to 5 % of power system capacity. Limits 3 and 4 apply switching loads from 10 % up to 170 % and down to 10 %, this condition representing switching loads that include motor loads.

4.2.1.2.2 Under conditions of busbar switching or transfer an interruption of the a.c. supply is likely to occur. The exact duration of the interruption will be defined in the individual system specification, but may be between 0 and 200 ms during which the voltage may be any value between zero and the applicable steady-state limits. Upon completion of the interruption, the equivalent step-function of the voltage transient shall be within limits 3 and 4 of figure 4.

4.2.1.3 ABNORMAL SYSTEM OPERATION

Limits 1 and 2 of figure 4 apply.

4.2.2 *Frequency*

4.2.2.1 GENERAL

Frequency transients shall be within the limits of figure 5 for all operations of the aircraft system.

4.2.2.2 NORMAL SYSTEM OPERATION

Limits 5 and 6 of figure 5 apply when switching loads from 5 % up to 85 % and down to 5 % of power system capacity; limits 3 and 4 apply when switching loads from 10 % up to 170 % and down to 10 %, this condition representing switching loads which include motor loads.

4.2.2.3 ABNORMAL SYSTEM OPERATION

Limits 1 and 2 of figure 5 apply.

5 VARIABLE FREQUENCY A.C. POWER SYSTEM CHARACTERISTICS (INCLUDING ROTORCRAFT APPLICATIONS)

NOTE — The characteristics below apply to the power at the utilization equipment terminals of a variable frequency system having a generator input speed ratio of 1 : 1,5. Where the speed is significantly different, suitably modified values of characteristics must be specified in the relevant aircraft system/equipment specification.

The voltage characteristics apply to line-to-neutral quantities; line-to-line characteristics should be as a result of the line-to-neutral values being as shown.

All a.c. voltage values are r.m.s values unless otherwise stated.

Transient surge r.m.s. voltages are derived from the recorded peak values.

5.1 Steady-state characteristics

5.1.1 *Voltage*

As 4.1.1.

5.1.2 *Phase displacement*

As 4.1.2.

5.1.3 *Voltage unbalance*

As 4.1.3.

5.1.4 *Voltage wave-form*

As 4.1.4.

5.1.5 *Voltage modulation*

As 4.1.5.

5.1.6 *Frequency*

The frequency of the power supplies shall be maintained within the limits 320 Hz and 480 Hz.

5.2 Transient characteristics (see also annex B)

5.2.1 *Voltage*

5.2.1.1 GENERAL

Surge voltages, when converted to their equivalent step-functions (see 8.1), shall be within the limits of figure 6 for all operations of the aircraft system. The most severe phase transient shall be used in determining conformity with this requirement.

In addition to surge voltages the switching of equipment will produce spike voltages. The test do demonstrate the ability of equipment to withstand spike voltages is specified in annex B.

5.2.1.2 NORMAL SYSTEM OPERATION

5.2.1.2.1 Limits 5 and 6 of figure 6 apply when switching loads from 5 % up to 85 % and down to 5 % of power system capacity. Limits 3 and 4 apply when switching loads from 10 % up to 170 % and down to 10 %, this condition representing switching loads that include motor loads.

5.2.1.2.2 Under conditions of busbar switching or transfer an interruption of the a.c. supply is likely to occur. The exact duration of interruption will be defined in the individual system specification, but may be between 0 and 200 ms during which the voltage may be any value between zero and the applicable steady-state limits. Upon completion of the interruption, the equivalent step-function of the voltage transient shall be within limits 3 and 4 of figure 6.

5.2.1.3 ABNORMAL SYSTEM OPERATION

Limits 1 and 2 of figure 6 apply.

5.2.2 *Frequency*

Changes in frequency shall be such that the rate of change of frequency does not exceed 65 Hz/s.

6 D.C. POWER SYSTEM CHARACTERISTICS

NOTE — The characteristics below apply to the power at the utilization equipment terminals.

All d.c. voltage values are mean values unless otherwise stated.

6.1 Steady-state characteristics

6.1.1 *Voltage*

The voltage shall be within the limits shown in table 4.

NOTES

1 Aircraft employing d.c. electric engine starters normally experience low d.c. system voltages during the starting cycle; equipment that is required to operate or be left switched on during this cycle should be so identified in the individual specification which should also define the appropriate voltage levels.

2 Equipment operated from a battery system with an integral battery charger may be subjected to voltages in excess of the values in table 4. Appropriate voltage levels should be specified in the individual equipment specification.

6.1.2 *Voltage ripple*

With no battery connected, ripple on the d.c. supply shall be such that the maximum departure from the mean d.c. level is less than 2 V, when measured in accordance with the requirements in 8.2.

The r.m.s. values of individual cyclic components of the ripple shall not exceed the values shown in figure 7.

6.2 Transient characteristics

6.2.1 *Voltage*

6.2.1.1 GENERAL

Surge voltages, when converted to their equivalent step functions, shall be within the limits of figure 8 for all operations of the aircraft system. The most severe transient shall be used in determining conformity with this requirement.

In addition to surge voltages the switching of equipment will produce spike voltages. The test to demonstrate the ability of equipment to withstand spike voltages is specified in annex B.

6.2.1.2 NORMAL SYSTEM OPERATION

6.2.1.2.1 Limits 5 and 6 of figure 8 apply when switching loads from 5 % up to 85 % and down to 5 % of power system capacity. Limits 3 and 4 apply when switching loads from 10 % up to 170 % and down to 10 %, this condition representing switching loads that include motor loads.

6.2.1.2.2 Under conditions of busbar switching or transfer, an interruption of the d.c. supply is likely to occur. The exact duration of the interruption will be defined in the individual system specification, but may be between 0 and 200 ms during which the voltage may be any value between zero and the applicable steady-state limits. Upon completion of the interruption, the equivalent step-function of the voltage transient shall be within limits 3 and 4 of figure 8.

6.2.1.3 ABNORMAL SYSTEM OPERATION

Limits 1 and 2 of figure 8 apply.

NOTE — Figure 8 represents transient surges on d.c. systems powered by wide speed range d.c. generators or by T.R.U.'s (transformer-rectifier-units) supplied from a variable frequency a.c. system. Where the power source is a T.R.U. supplied from a constant frequency a.c. system, reduced transient surges will result as indicated in figure 9.

7 UTILIZATION EQUIPMENT

NOTE — This clause details limits for those aspects of utilization equipment which may adversely affect the characteristics of electrical power supplied to other equipment.

7.1 Power requirements

The specification for the utilization equipment shall state which of the types of power listed herein is required. Unless the use of both a.c. and d.c. power will provide a significant advantage in reliability, cost or weight, utilization equipment should obtain power exclusively from one type of supply. Equipment using both a.c. and d.c. input power shall give specified performance when subjected to simultaneous variations of a.c. and d.c. power within the limits shown in clauses 4 or 5, and 6. The loss of either power supply shall not result in an unsafe condition.

7.2 Conversion

Equipment which requires power with characteristics differing from those of the main supply shall accept the power as defined herein and convert it by means of devices integral with or ancillary to the utilization equipment or system.

7.3 Performance

The equipment shall give its specified performance when supplied with the appropriate power having the ranges of characteristics specified in clauses 3, 4, 5 and 6, unless the individual equipment specification permits degradation in specific regions of system operation. Any malfunction that results from the interruption of the input power for any period up to 0,2 s shall be declared. The equipment shall be capable of withstanding the abnormal steady-state limits of voltage (see tables 3 and 4) without damage, and shall automatically return to normal operation when the system returns to normal steady-state limits (NSSL).

Failure of one phase of the supply or of the equipment supplied from three-phase power shall not result in an unsafe condition. The individual specification shall define the characteristics constituting an unsafe condition.

The equipment shall withstand the transient voltage test specified in annex B.

7.4 Influence on electrical systems

In order to limit influence by utilization equipment which would tend to cause the characteristics of power at the input terminals to go beyond the limits specified in clauses 4, 5 and 6 :

1) where the line current in a.c. equipment exceeds 5 A it shall be such that the r.m.s. value of the total harmonic content does not exceed 10 % of the fundamental r.m.s. current, unless otherwise agreed with the aircraft system designer;

2) for equipment in which the load is pulsed, the rate and magnitude of current variation shall be minimized and shall be agreed with the aircraft system designer;

3) equipment shall preferably be so designed that it does not feed back direct current to the supply system (for example, half-wave rectification of a phase supply). Departures from this requirement shall be agreed with the aircraft system designer.

7.5 A.C. power

7.5.1 *Three-phase*

For loads rated at 500 VA or more, three-phase power shall be used, unless otherwise agreed with the aircraft system designer.

7.5.2 *Single-phase*

For loads rated at less than 500 VA, single-phase power shall normally be used. Equipment consuming more than 500 VA, which is inherently single-phase in power requirement, shall present, if practicable, a three-phase demand by being internally segregated into three single-phase loads. Single-phase loads shall normally be connected between line and neutral.

7.5.3 *Phase load balance*

Three-phase equipment shall require equal phase volt-amperes as far as is practicable. Where there is a significant difference between the phase loadings, the limits shall be agreed with the aircraft system designer.

7.5.4 *Power factor*

Under steady-state conditions, the power factor of a.c. equipment shall be as near unity as is practicable; the full load power factor on the worst phase shall not be less than that shown in figure 10.

7.6 Standby (warm-up) power

For those modes of equipment operation in which performance is not required but power is needed to maintain the equipment at readiness, the power requirements should be kept to a minimum.

8 EXPLANATORY NOTES

8.1 Voltage transients

The several voltage transient curves given in this International Standard are not intended to represent actual surges; they are the envelopes of the step-functions for all likely surges from which voltage levels for purposes of design and/or test can be taken.

The spike voltage wave-form given in annex B is not intended to represent actual spikes but is the envelope within which all likely spikes may be assumed to be enclosed for the purposes of design and test.

8.2 Voltage ripple

The voltage ripple appearing on the supply shall be measured using a calibrated wide-band oscilloscope (10 MHz minimum) at a sweep time of 2,5 ms. An oscillogram shall be made. The peak ripple voltages shall not exceed the mean d.c. voltage by more than 2 V for either polarity.

8.3 Equivalent step-functions of transient surges

An equivalent step-function is a reasonable r.m.s. equivalent of a transient voltage surge. The curves indicate the time duration for which the peak voltage of an actual surge should be applied to give the same effect as the whole surge. A typical example of conversion of a transient surge to its equivalent step-function is shown in figure 11.

8.4 Steady-state voltage limits

Tables 3 and 4 define the normal, abnormal and emergency values of voltage to which utilization equipment will be exposed during steady-state operation.

These voltage limits take into account the following factors :

1) the control limits of busbar voltage under balanced load conditions;

2) the effect on busbar voltage of unbalanced system load;

3) an allowance for the voltage drop in the utilization equipment supply cables.

NOTE — For three-phase equipment with unbalanced loads see also 7.5.3.

The abnormal steady-state limits take into account the extreme limits of under- and over-voltage protection devices (see also the note in 2.6).

The build-up of these tolerances is given in tables 1 and 2.

TABLE 1 — **Derivation of a.c. voltage limits**

A.C. equipment	Main system V	Emergency system V
Power source busbar voltage	112 to 118	108 to 122
Volt drop	− 4, + 0	− 4, + 0
Normal steady-state limits (NSSL)	108 to 118	–
U-V and O-V trip band limits	− 10 + 14	–
Abnormal steady-state limits (ASSL)	98 to 132	–
Emergency steady-state limits (ESSL)	–	104 to 122

TABLE 2 — **Derivation of d.c. voltage limits**

D.C. equipment	Main system V	Emergency system V
Power source busbar voltage	26 to 29	20 to 29
Volt drop	− 2, + 0	− 2, + 0
Normal steady-state limits (NSSL)	24 to 29	–
U-V and O-V trip band limits	± 3	–
Abnormal steady-state limits (ASSL)	21 to 32	–
Emergency steady-state limits (ESSL)	–	18 to 29

TABLE 3 — **Steady-state a.c. voltage limits**

Individual phase			Average of the three individual phases		
Normal (NSSL)	**Abnormal** (ASSL)	**Emergency** (ESSL)	**Normal** (NSSL)	**Abnormal** (ASSL)	**Emergency** (ESSL)
V	V	V	V	V	V
108 to 118	98 to 132	104 to 122	109,5 to 116,5	100 to 130	106 to 120

TABLE 4 — **Steady-state d.c. voltage limits**

Normal (NSSL)	**Abnormal** (ASSL)	**Emergency** (ESSL)
V	V	V
24 to 29	21 to 32	18 to 29

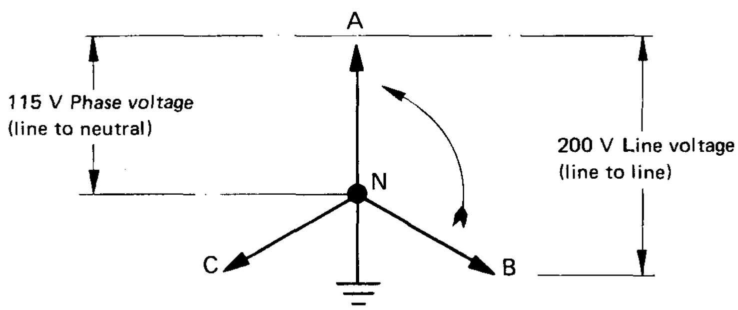
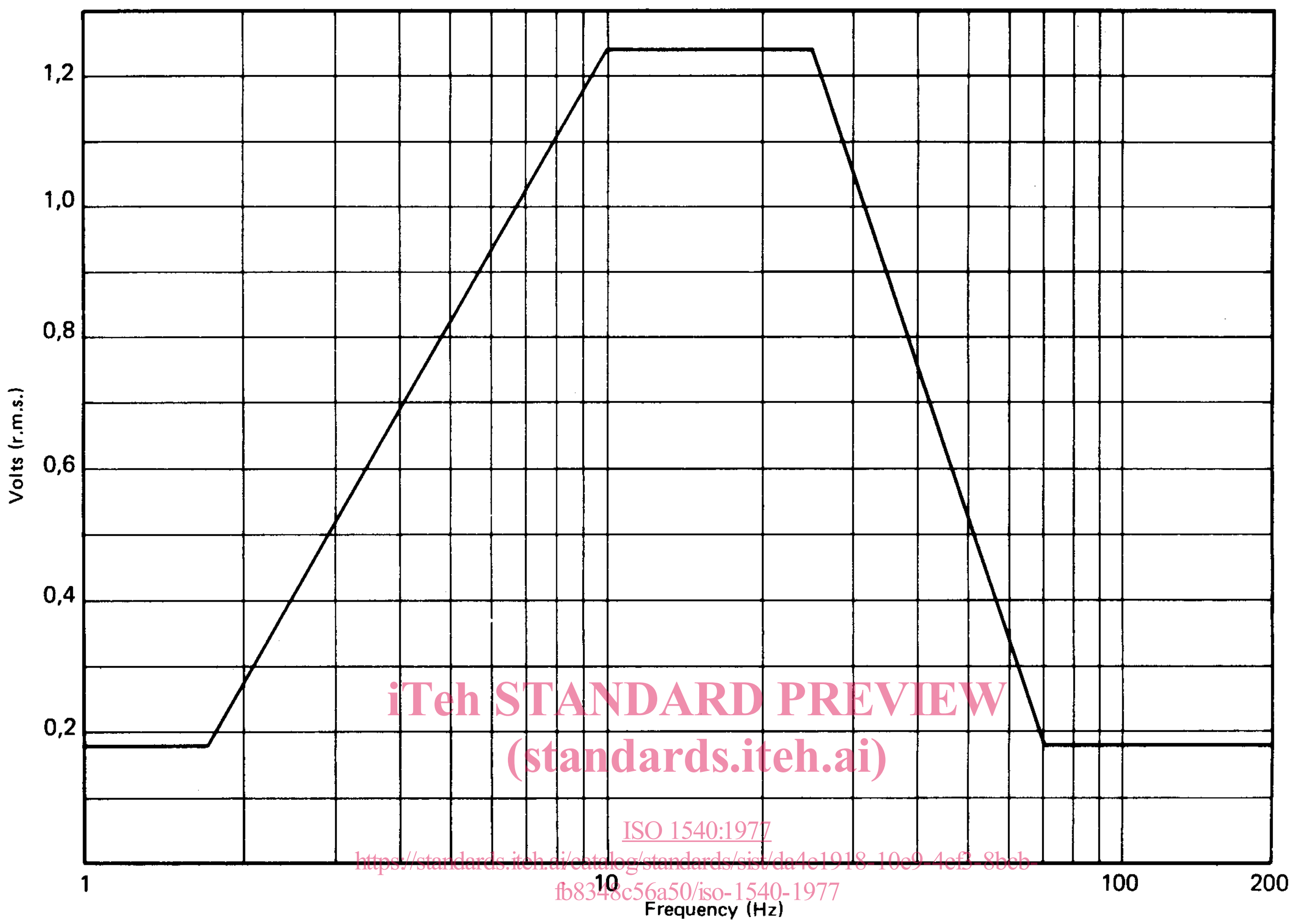


FIGURE 1 — **Diagram of phase sequence and line designations**



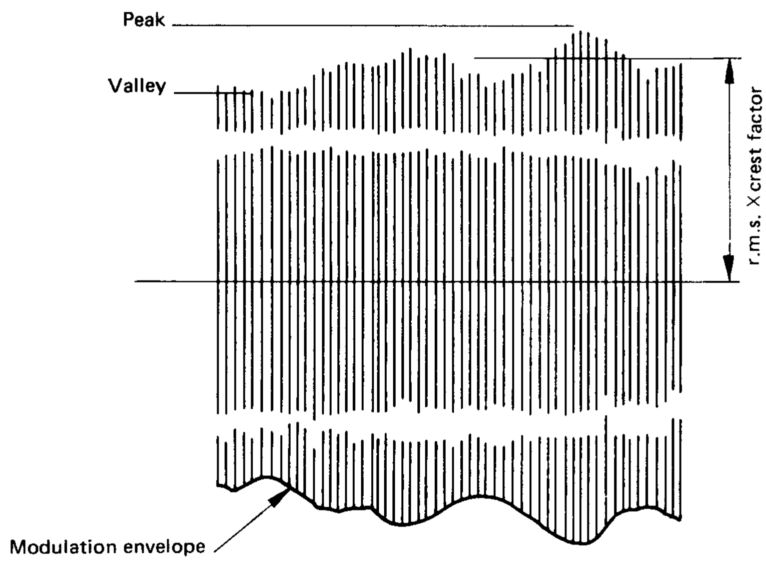


FIGURE 2 — **R.M.S. voltage of components of voltage modulation envelope**

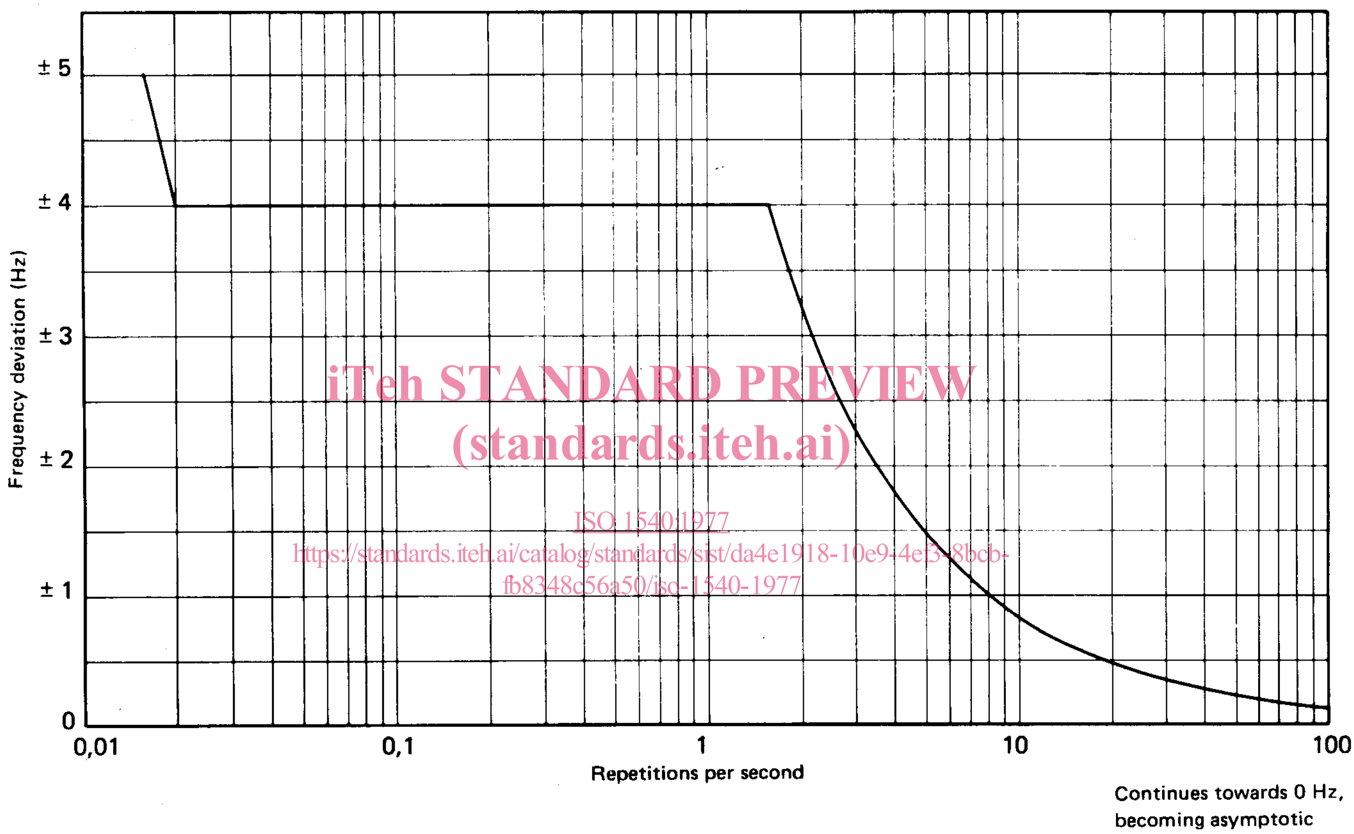


FIGURE 3 – **Characteristics of a.c. frequency modulation**