

INDHOLD

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INDLEDNING

AC måleteknik er udarbejdet i forbindelse med udviklingen af Multimeter MM2.

Multimeter MM2 er udstyret med en række features i forbindelse med AC målinger.

Beskrivelsen tager udgangspunkt i det generelle og er som sådan ikke direkte releteret til MM2.

Omtalen er begrænset til lavfrekvensområdet op til ca. 1 MHz.

INTRODUCTION

“AC Measurement Techniques” has been prepared in connection with the development of the Multimeter MM; The Multimeter MM2 has a number of features for AC measurements. This description is general in its approach and is therefore not directly related to the MM2. The subject matter is limited to the low-frequency range up to about 1 MHz.

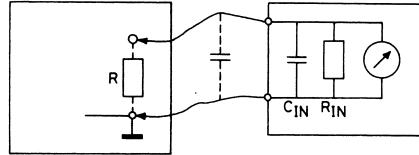
GENEREL MÅLETEKNIK

Ved måling af AC signaler er der en række forhold, som man bør tage hensyn til.

Det er vigtigt at vide, hvordan der skal måles.

Alle målinger skal udføres på en sådan måde, at måleopstillingen påvirkes mindst mulig.

Måleopstilling/
Measuring set up



AC Voltmeter/
AC Voltmeter

Alle målinger sker over en impedans.

For ikke at belaste måleopstillingen skal $R_{in} \gg R$.

Ved højere frekvenser skal man også sørge for, at C_{in} ikke belaster måleopstillingen utilsigtet.

C_{in} er typisk 20-40 pF for et AC voltmeter, men hertil skal lægges kabelkapaciteten.

Kapaciteten i et skærmet kabel er typisk 100-200 pF/meter.

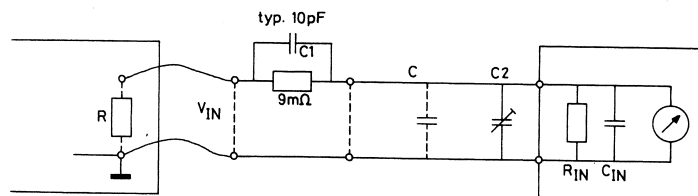
D.v.s. at den samlede indgangskapacitet typisk ligger på 120-250 pF.

Ved 100 kHz svarer denne kapacitet til en impedans på 6-13 k Ω .

For de fleste AC voltmeter er R_{in} valgt til 1 M Ω , men som det ses, er impedansen væsentlig lavere p.g.a. kapaciteterne. Derfor skal R i måleopstillingen virkelig være lavimpedant, selv ved moderate frekvenser.

Problemet kan afhjælpes ved at anvende en 1:10 probe.

Måleopstilling/
Measuring set up



AC Voltmeter/
AC Voltmeter

Måleopstillingen bliver nu ren DC mæssigt belastet med 10 M Ω .

Den kapacitive belastning bliver C_1 i serie med

$C_{kabel} // C_2 // C_{in}$.

Den samlede kapacitet af serieforbundne kondensatorer er mindre end den mindste.

Derfor er den samlede kapacitive belastning i størrelsesordenen 6-12 pF.

Impedansen af denne kapacitet er ved f.eks. 100 kHz 130-260 k Ω . Altså en klar forbedring i forhold til den direkte tilslutning.

GENERAL MEASUREMENT TECHNIQUES

When measuring AC signals there are a number of factors which need to be taken into account.

It is important to know how to measure.

All measurements should be made in such a way that the measuring set-up is influenced as little as possible.

All measurements are made via an impedance.

To avoid loading the measuring set-up, $R_{in} \gg R$.

At higher frequencies it should also be ensured that C_{in} does not inadvertently load the measuring set-up.

C_{in} is typically 20-40 pF for an AC voltmeter, but to this must be added the cable capacitance.

The capacitance in a screened cable is typically 100-200 pF/metre.

That means that the total input capacitance will typically be 120-250 pF.

At 100 kHz this capacitance corresponds to an impedance of 6-13 k Ω .

On most AC voltmeters R_{in} is set at 1 M Ω , but as can be seen, the impedance is substantially lower because of the capacitances. Therefore R in the measuring set-up should really be at a low impedance, even at moderate frequencies.

The problem can be remedied by using a 1:10 probe.

The measuring set up is now subject to a purely DC load of 10 M Ω .

The capacitive load is C_1 in series with $C_{cable} // C_2 // C_{in}$.

The total capacitance of capacitors connected in series is lower than the lowest.

Therefore the total capacitive load is of the order of magnitude 6-12 pF.

The impedance of this capacitance is, for example, 130-260 k Ω at 100 kHz. An obvious improvement therefore when compared with the direct connection.

Ulemper ved anvendelse af 1:10 proben er selvfølgelig, at spændingen bliver delt med 10, og at det aflæste resultat skal ganges med 10 for at få det korrekte resultat.

Endvidere er det nødvendigt at justere »C₂«, da 10-delingen ved høje frekvenser er bestemt af forholdet mellem C₁ og C_{kabel}//C₂//C_{in}.

Denne tilpasning af C₂ skal selvfølgelig ske, mens proben er tilsluttet AC voltmeteret.

Den nemmeste måde at justere proben på er ved at måle en firkant spænding f.eks. 1 kHz.

Voltmeteret stilles i korrekt måleområde f.eks. 200 mV.

Et oscilloskop tilsluttes AC OUT (findes på bl.a.

RV9A og MM2).

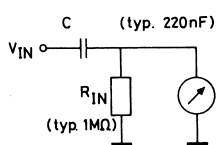
C₂ justeres til korrekt firkantgengivelse på oscilloskopet, ingen »undershoot« eller »overshoot«.

The drawback of using the 1:10 probe is, of course, that the voltage is divided by 10 and the reading must be multiplied by 10 to obtain the correct result. It is also necessary to adjust 'C₂', as dividing by 10 at high frequencies is determined by the ratio of C₁ to C_{cable}/C₂//C_{in}.

This adjustment of C₂ should, of course, be made while the probe is connected to the AC voltmeter.

The easiest way of adjusting the probe is by measuring a square-wave voltage, e.g. 1 kHz. The voltmeter should be set to the correct measuring range, e.g. 200 mV. An oscilloscope should be connected to AC OUT (to be found on the RV9A and MM2 among others).

C₂ should be adjusted to the correct squarewave output on the oscilloscope with no undershoot or overshoot.



For at hindre DC signaler i at påvirke måleresultatet, er alle AC voltmetre forsynet med en kondensator i serie med indgangen.

R/C-ledet R_{in} og C_{serie} har typisk en knækfrekvens på 1 Hz.

Indeholder målesignalet evt. en DC bliver den selvfølgelig blokeret af kondensatoren. Den aflæste måleværdi er således kun et udtryk for AC spændingen i målesignalet. Eksempler på disse forhold er beskrevet under afsnittet »Kurveformer«.

Måles der på meget svage signaler (mV eller μV), skal der udvises stor opmærksomhed for at opnå et pålideligt resultat.

Man skal være opmærksom på måleudstyrets egenstøj, som typisk er i størrelsesordenen nogle μV (10-30 μV).

En anden ting, der kan have indflydelse, er egenstøj fra komponenter. F.eks. har alle modstande en egenstøj, der er afhængig af modstandens ohmske værdi og båndbredden af signalet.

Eksempelvis en 10 kΩ modstand og en signalbåndbredde på 1 MHz: V_{støj} = 13 μV.

Det betyder at måling over en stor båndbredde, skal foretages lavimpedant.

To prevent DC signals influencing the measuring result, all AC voltmeters have a capacitor fitted in series with the input.

The R-C network R_{in} and C_{serie} typically has a cut-off frequency of 1 Hz.

If the measuring signal were to contain a DC, it would of course be blocked by the capacitor. The reading is therefore only an expression of the AC voltage in the measuring signal. Examples of this ratio are described in the section "Curve forms".

If a very weak signal (mV or μV) is being measured, great care must be taken to obtain a reliable result. Attention must be paid to the inherent noise of the measuring equipment, which is typically of the order of magnitude of a few μV (10-30 μV).

Another factor which can have an effect is the inherent noise of components. All resistors, for example, have inherent noise which is dependent on the ohmic value of the resistor and the band width of the signal. By way of example, a 10 kΩ resistor and a signal band width of 1 MHz: V_{noise} = 13 μV.

This means that measurements over a broad band width should be done with a low impedance.

Den nøjagtige sammenhæng er:

$$V_{\text{støj}} = \sqrt{4KTR} \text{ V} / \sqrt{\text{Hz}} \quad (\text{Formel 1})$$

$$= 0,13 \times 10^{-9} \sqrt{R \times \text{BW}} \quad (T = 25^{\circ}\text{C})$$

K – Boltzmannkonstant = $1,37 \times 10^{-23}$

T – Temperatur i Kelvin

R – Modstand i Ω

BW – Båndbredde i Hz (f_{øvre} – f_{nedre})

The exact correlation is as follows:

$$V_{\text{noise}} = \sqrt{4KTR} \text{ V} / \sqrt{\text{Hz}} \quad (\text{Equation 1})$$

$$= 0.13 \times 10^{-9} \sqrt{R \times \text{BW}} \quad (T = 25^{\circ}\text{C})$$

K – Boltzmann constant = 1.37×10^{-23}

T – Temperature in Kelvin

R – Resistance in Ω

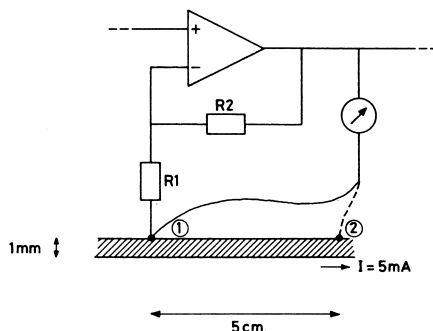
BW – Bandwidth in Hz (f_{upper} – f_{lower})

Den faktor, der i praksis volder de største problemer, er stelforbindelsen.

Måles der på svage signaler, er det altafgørende, at der måles i forhold til en korrekt stel.

The factor which causes the greatest problems in practice is the ground connection.

If weak signals are being measured, it is vital that the measurements be made in relation to a correct earth.



Den korrekte tilslutning er selvfølgelig i punkt »1«. Tilsluttes der i punkt »2«, kan der opstå en målefejl. Som et taleksempel kan nævnes en printbane 1 mm bred og 5 cm lang (alm. 35 μm kobbertykkelse), hvor der går en strøm på blot 5 mA. Den ohmske modstand og strømmen giver i dette tilfælde en spændingsfald på mere end 100 μV .

I større måleopstillinger med både analoge og digitale kredsløb skal man være opmærksom på, at der normalt findes flere adskilte stel.

I sådanne kredsløb er det specielt vigtigt, at der måles i forhold til korrekt stel (f.eks. analog stel). Digitale stelveje er ofte meget støjfyldte p.g.a. ekstrem hurtige skiftetider i de digitale systemer.

The correct connection is of course to point '1'.

If the connection is made to point '2', a measuring error could occur.

An example using figures would be a conductor lane 1 mm across and 5 cm long (ordinary 35 μm copper thickness), with a current of just 5 mA. The ohmic resistance and the current produce in this case a voltage drop of more than 100 μV .

With large measuring set-ups with both analog and digital circuits it should be noted that there are normally several separate ground. With such circuits it is particularly important that measurements are made in relation to a correct ground (e.g. analog ground). Digital ground paths are often very noisy because of extremely rapid shift times in digital systems.

BEGREBER

I forbindelse med AC målinger anvendes en række begreber, som det er nyttig at kende. RMS (effektivværdi), AVG (middelværdi) og PEAK (spidsværdi) omtales i næste afsnit.

TERMS

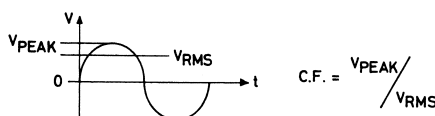
There are a number of terms used in connection with AC measurements which it is useful to know. RMS (root-mean-square value), AVG (mean value) and PEAK (peak value) will be discussed in the next section.

Crest Faktor

C.F. er forholdet mellem spidsværdien (PEAK) og effektivværdien (RMS).

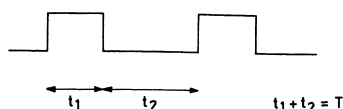
Crest factor

C.F. is the ration of the peak value (PEAK) to the root-mean-square value (RMS).



Duty Cycle

Duty cycle



For en firkant er »Duty cycle« = t_1/T , opgives oftest i %, d.v.s. $t_1/T \times 100\%$.
Puls/pause forholdet er t_1/t_2 .

Formfaktor

Formfaktoren er defineret som forholdet mellem V_{RMS}/V_{AVG} .

Rise time/Fall time

Udtrykket rise- og fall time anvendes i forbindelse med den tid signaler er om at skifte fra et niveau til et andet, f.eks. 0 til 1 Volt.

Normalt anvendes begrebet til, at beskrive flanker på f.eks. firkantkurver, men kan anvendes generelt.

For a square wave the duty cycle = t_1/T , usually stated in %, i.e. $t_1/T \times 100\%$. The pulse-pause ratio is t_1/t_2 .

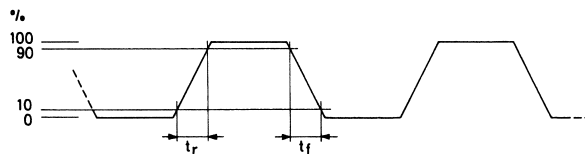
Form factor

The form factor is defined as the ration $V_{RMS}: V_{AVG}$.

Rise time/fall time

The terms rise time and fall time are used in connection with the time signals take to change from one level to another, e.g. 0 to 1 Volt.

Normally the terms are used to describe edges on, for example, a square pulse curve, but they can be used generally.



Rise time, t_r er defineret som den tid signalet er om at stige fra 10-90% af hele springet.

Fall time, t_f er tilsvarende defineret som den tid signalet er om at falde fra 90-10% af hele springet.

Fall time omtales ofte som »rise time« for negative flanker.

The rise time, t_r , is defined as the time the signal takes to rise from 10-90% of the full pulse height. The fall time, t_f , is correspondingly defined as the time the signal takes to decay from 90-10% of the full pulse height.

The fall time is frequently referred to as the rise time for trailing edges.

Rise time begrebet indgår i en meget anvendelig formel:

$$t_r \times f_{\text{øvre}} = 0,35 \text{ (formel 2)}$$

det gælder for et førsteordens system, med den øvre knæfrekvens (-3 dB) $f_{\text{øvre}}$.

The rise time term is included in a very useful equation:

$$t_r \times f_{\text{upper}} = 0.35 \text{ (equation 2)}$$

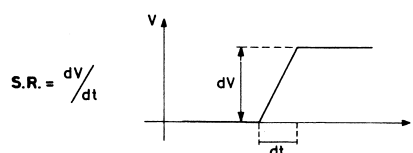
which applies to a system of the first order with the upper cut-off frequency (-3 dB) f_{upper} .

Slew rate

Slew rate, S.R. benyttes også til at beskrive et skift, typisk på en firkant. S.R. er defineret som spændingsændringen pr. tidsenhed, og opgives normalt i $V/\mu\text{Sec}$.

Slew rate

Slew rate, S.R., is also used to describe a shift, typically in a square pulse. S.R. is defined as the voltage change per unit of time and is usually given in $V/\mu\text{Sec}$.



Forskellen mellem begreberne slew rate og rise time er, at rise time ikke siger noget om spændings-springets størrelse.

The difference between the terms slew rate and rise time is that the rise time does not say anything about the size of the voltage rise.

DETEKTORTYPER

Et AC signal varierer pr. definition hele tiden i spænding. Derfor må der findes en måde at vise signalet på (viserinstrument eller digital voltmeter), som muliggør en konstant visning.

Til at sikre dette findes en række principielt forskellige metoder.

Her omtales de tre metoder, der i praksis anvendes, og som hver for sig har forskellige egenskaber.:

RMS »Root Mean Square«, også kaldet effektivværdi.

AVG »Average«, middelværdi.

PEAK Spidsværdi.

RMS

Effektivværdien for et signal er defineret som:

$$V_{\text{RMS}} = \sqrt{\frac{1}{T} \int_0^T [v(t)]^2 dt} \quad (\text{Formel 3})$$

Udtrykt i ord: signalet skal kvadreres, derefter midles over en tidskonstant, T, og tilsidst uddrages kvadratroden.

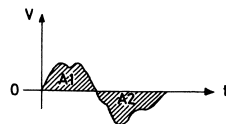
I praksis udtrykker V_{RMS} , hvor stor en DC spænding der skal påtrykkes en given modstand, for at afsætte en effekt, der er lig med den effekt, som den målte spænding vil afsætte i den givne modstand.

F.eks. afsætter 1 V_{RMS} og 1 V_{DC} samme effekt i en given modstand.

Da RMS værdien er et udtryk for energiindholdet i signalet, er RMS detektoren den mest foretrukne, når et voltmeter kun er forsynet med en detektor.

Et AC voltmeter måler selvfølgelig kun AC og ikke DC, så længe målesignalet kun indeholder AC komponenter. D.v.s. signalet ligger med lige store arealer under og over 0 volt,

Hvis $A_1 = A_2$ indholder signalet ingen DC.



If $A_1 = A_2$, the signal contains no DC.

Indeholder målesignalet en DC komponent, filtreres den bort af seriekondensatoren i indgangen (se side 03), og AC voltmeteret viser RMS værdien af AC indholdet.

DETECTOR TYPES

By definition, an AC signal varies all the time in voltage. Therefore, a way must be found of showing the signal (moving-coil meter or digital voltmeter), which makes a constant reading possible.

For this purpose there are a number of different methods, which differ in principle. Here we shall be looking at three methods, which are used in practice and each of which has different properties:

RMS "Root Mean Square", also called the effective value.

AVG 'Average', mean value.

PEAK Peak value.

RMS

The effective value is defined as:

$$V_{\text{RMS}} = \sqrt{\frac{1}{T} \int_0^T [v(t)]^2 dt} \quad (\text{equation 3})$$

In words: the signal must be squared, then averaged over a time constant, T, and finally the square root obtained.

In practice, V_{RMS} expresses the size of DC voltage which has to be applied to a given resistance to dissipate a power equal to the power which the voltage under measurement will dissipate in the given resistance.

E.g. 1 V_{RMS} and 1 V_{DC} dissipate the same power in a given resistance.

As the RMS value is an expression of the energy content in the signal, the RMS detector is the type most frequently preferred for voltmeters which only have one detector.

An AC voltmeter only measures AC, of course, and not DC as long as the signal under measurement only contains AC components. I.e. the signal has areas of equal size above and below 0 Volt, e.g. a sinusoidal curve.

If the signal under measurement contains a DC component, it is filtered out by the series capacitor in the input (see page 03) and the AC voltmeter shows the RMS value of the AC content.

Ønskes den totale RMS værdi (AC + DC), findes den som:

$$V_{\text{RMS, TOTAL}} = \sqrt{V_{\text{DC}}^2 + V_{\text{RMS, AC}}^2} \quad (\text{Formel 4})$$

Forskellen mellem en række typiske AC og DC koblede signaler kan ses i afsnittet omkring »kurveformer«.

Tilsvarende kan summen af to AC signaler findes som:

$$V_{\text{RMS, SUM}} = \sqrt{V_{\text{AC1}}^2 + V_{\text{AC2}}^2} \quad (\text{Formel 5})$$

Denne sammenhæng benyttes også til vurdering af støjs indflydelse på måleresultatet.

Alle kredsløb har en egenstøj.

Da egenstøjen og målesignalet skal »adderes kvadratisk«, skal målesignalet blot være nogle få gange større end egenstøjen, for at det ikke »ses« på resultatet.

F.eks. egenstøj: 50 µV og målesignal: 500 µV (10 gange egenstøjen) bliver det aflæste resultat:

$$V = \sqrt{50^2 + 500^2} = 502,5 \mu\text{V},$$

hvilket blot er en afvigelse på 0,5 %.

Ved konstruktionen af RMS konvertere skal der fastlægges en tidskonstant (T i formel 3).

Her må der nødvendigvis indgås et kompromis.

Vælges en stor tidskonstant tager det lang tid før målingen falder til ro, til gengæld kan der måles på meget lave frekvenser med god nøjagtighed.

Vælges en kort tidskonstant bliver aflæsningen hurtig, men nøjagtigheden bliver mindre ved lave frekvenser.

Tidskonstanten vælges normalt i området 10-300 mSec.

Avancerede instrumenter, som f.eks. Bang & Olufsen NM1, har indbygget flere forskellige tidskonstanter, som brugeren frit kan vælge mellem.

I instrumenter, hvor der er valgmulighed mellem flere detektor typer, vælges RMS typisk som udgangspunkt, da »RMS-en« altid er entydig.

Grunden til, at ikke alle instrumenter er udstyret med RMS detektor, er hovedsagelig et økonomisk spørgsmål. RMS konvertere er væsentlig dyrere end f.eks. en middelværdidetektor.

If the total RMS value (AC + DC) is required, it is found as:

$$V_{\text{RMS, TOTAL}} = \sqrt{V_{\text{DC}}^2 + V_{\text{RMS, AC}}^2} \quad (\text{equation 4})$$

The difference between a number of typical AC and DC connected signals can be seen in the section on »curve forms».

Correspondingly, the sum of two AC signals can be found as:

$$V_{\text{RMS, SUM}} = \sqrt{V_{\text{AC1}}^2 + V_{\text{AC2}}^2} \quad (\text{equation 5})$$

This correlation is also used to assess the influence of noise on the measuring result.

All circuits have inherent noise.

As the inherent noise and the measuring signal should be »added quadratically«, the measuring signal only needs to be a few times larger than the inherent noise for it not to be 'seen' in the result.

E.g. with inherent noise: 50 µV and measuring signal: 500 µV (10 times the inherent noise) the reading will be:

$$V = \sqrt{50^2 + 500^2} = 502.5 \mu\text{V},$$

which is a deviation of just 0.5 %.

When designing RMS converters, a time constant should be set (T in equation 3).

A compromise has to be made here.

If a large time constant is selected, it takes a long time for the measurement to settle down, though low frequencies can be measured with good accuracy.

If a short time constant is selected, a reading is obtained quickly, but the accuracy is reduced at low frequencies.

The time constant is usually set in the range 10-300 mSec.

Advanced instruments, such as the Bang & Olufsen NM1, for example, have several different time constants built in, allowing the user to choose freely between them.

In instruments where it is possible to choose between several detector types, RMS is typically chosen as the starting point, as the RMS value is always unambiguous.

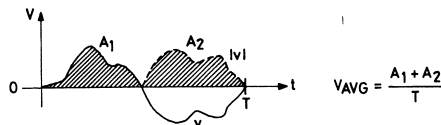
The reason why not all instruments are equipped with an RMS detector is primarily an economic one. RMS converters are much more expensive than, for example, a mean value detector.

AVG

Middelværdien af et AC signal findes som:

$$V_{AVG} = \frac{1}{T} \int_0^T [v(t)]^2 dt \quad (\text{formel 6})$$

Årsagen til at det er den numeriske værdi af signalet, der integreres, er at et integreret det rene signal, findes. DC'en, som jo er 0 i en AC koblet opstilling.



Måles middelværdien på en sinuskurve med en RMS på 1.000, vil resultatet blive 0.900 ($2 \cdot \sqrt{2/\pi}$).

Det er normalt RMS værdien, der ønskes, derfor kalibreres de fleste middelværdivisende instrumenter til at vise 1,111 gange middelværdien, således at der viser 1.000 Volt for 1.000 Volt RMS.

Et sådant instrument siges at være »RMS sinus kalibreret« eller lignende.

Så længe der blot måles på sinusformede signaler, vil alt være i orden.

For andre signalformer vil et sådant instrument ikke længere vise RMS værdien, men blot 1,111 gange middelværdien.

I afsnittet »Kurveformer« er der vist en række eksempler på, hvor stor fejlen er for en række udvalgte kurveformer.

Fordelen ved middelværdivisende instrumenter er den relative enkle (og økonomisk overkommelig) opbygning. Ligeledes kan der opnås en god nøjagtighed over et bredt frekvensområde, hvilket kan være et problem for RMS detektorer.

Ved de allerfleste målinger er det sinusformede kurver, der skal måles på, og her er et middelværdivisende instrument fuldt tilstrækkeligt. Og hvis der måles på lidt højere frekvenser (>100 kHz), kan der ofte opnås en bedre nøjagtighed end ved en RMS måling.

Begrænsningen for middelværdivisende instrumenter er mere komplekse kurveformer, f.eks. kurver fra styrede ensrettede (triacs m.v.), hvor der virkelig skal udvises stor opmærksomhed for at opnå et korrekt resultat (se f.eks. afsnittet »Eksempel 1«).

Måles der på en kendt kurveform (f.eks. firkant, trekant osv.), kan målefejlen i forhold til RMS bestemmes (se »Kurveformer«), således at der kan korrigeres.

AVG

The mean value of an AC signal is found as:

$$V_{AVG} = \frac{1}{T} \int_0^T [v(t)]^2 dt \quad (\text{equation 6})$$

The reason for it being the numerical value of the signal which is integrated, is that if the pure signal is integrated, the DC is found, which is in fact 0 in an AC connected set-up.

If the mean value of a sine curve with an RMS of 1.000 is measured, the result will be 0.900 ($2 \cdot \sqrt{2/\pi}$).

It is usually the RMS value that is required, and therefore most mean value indication instruments are calibrated to show 1.111 times the mean value, so that 1.000 Volt is shown for 1.000 Volt RMS.

Such an instrument is said to be "RMS-sine calibrated" or similar.

As long as only sinusoidal signals are measured, all will be well.

For other signal forms, such an instrument will no longer show the RMS value but just 1.111 times the mean value.

The section "Curve shapes" shows a number of examples of how large the error is for a number of selected curve forms.

The advantage of instruments which show the mean value is their relatively simple (and inexpensive) design.

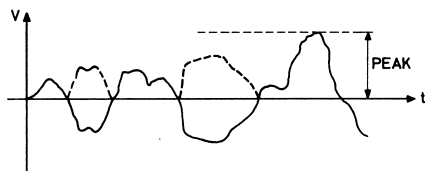
They also give good accuracy over a wide range of frequencies, which can be a problem with RMS detectors.

In the majority of cases, it is a sinusoidal curve which is to be measured and a mean value instrument is quite adequate for this. And where slightly higher frequencies are being measured (>100 kHz), it can often give better accuracy than an RMS measurement. Mean value instruments reach their limits with more complex curve forms, e.g. curves from controlled rectifiers (triacs etc), where great care really has to be taken to obtain a correct result (see e.g. the section "Example 1").

If a known curve form is being measured (e.g. square, triangular etc.), the measuring error in relation to the RMS can be determined (see "Curve forms") so that it can be corrected.

PEAK

Ved spidsværdi målinger er der to principielt forskellige metoder, »peak« og »peak – peak«:



»Peak« målingen finder den numerisk største værdi, medens »peak – peak« finder den højeste værdi minus den laveste værdi.

For symmetriske signaler er »peak – peak« = $2 \times$ »peak«.

Her skal blot omtales »peak« målingen.

Der er selvfølgelig en grænse for, hvor hurtigt en peak detektor kan reagere.

Den spids, der skal måles, må nødvendigvis have en vis tidsmæssig udstrækning.

Som mål for detektorens hurtighed benyttes opladetidskonstanten τ_{OP} .

Ligeledes opgives normalt en afladetidskonstant τ_{NED} , som angiver, hvor lang tid detektoren er om at falde til ca. 37% af den målte spidsværdi, efter at signalet er fjernet fra indgangen.

De aller fleste peak målende instrumenter kan inddeles i to grupper:

1. τ_{OP} er gjort så lav som muligt, typisk nogle $\mu\text{Sec.}$, og τ_{NED} er gjort så stor som muligt, typisk adskillige sec. eller min.
Kaldes ofte for »peak-hold«.
2. $\tau_{OP} = 1 \text{ mSec.}$ og $\tau_{NED} = 250 \text{ mSec.}$, svarende til tidskonstanterne i den såkaldte Quasi – Peak detektor.

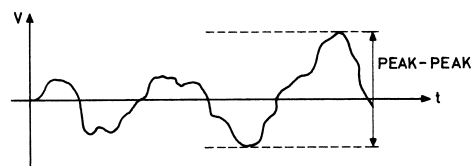
Måles der på engangsfænomener, er type 1 klart at foretrække, mens ved målinger på periodiske signaler er type 2 mest velegnet.

Ved type 2 (Quasi-Peak) skal man være opmærksom på, at hvis der måles på meget lave frekvenser, hvor periodetiden ($1/\text{frekvens}$) er af samme størrelsesorden som afladetidskonstanten, vil den aflæste værdi være lavere end den absolutte spidsværdi.

Til gengæld har type 2 den fordel, at den ikke er så hysterisk overfor støjpulser m.v. som type 1.

PEAK

When measuring peak values there are basically two different methods, 'peak' and "peak – peak":



The 'peak' method finds the numerically largest value, while "peak – peak" finds the highest value minus the lowest value. In the case of symmetrical signals "peak – peak" is $2 \times$ 'peak'.

Only the 'peak' method is to be considered here.

There is of course a limit to how quickly a peak detector can react. The peak to be measured must of necessity last a certain amount of time.

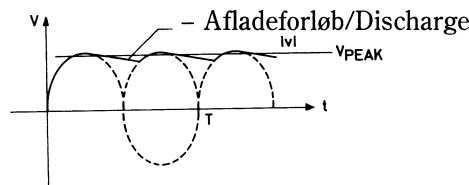
A charge time constant τ_{UP} is used as a measure of the detector's speed. Likewise, a discharge time constant τ_{DOWN} is stated, which specifies the amount of time the detector takes to drop to approx. 37% of the measured peak value after the signal has been removed from the input.

By far the majority of instruments which measure peaks can be divided into two groups:

1. τ_{UP} is made as short as possible, typically a few $\mu\text{Sec.}$, and τ_{DOWN} is made as large as possible, typically several seconds or minutes.
Often called "peak-hold".
2. $\tau_{UP} = 1 \text{ mSec.}$ and $\tau_{DOWN} = 250 \text{ mSec.}$, corresponding to the time constants in what is called the quasi-peak detector.

If one-off phenomena are being measured, type 1 is clearly to be preferred, while type 2 is most suitable for measuring periodic signals.

When using type 2 (quasi-peak) it should be noted that if very low frequencies are being measured, in which the period ($1/\text{frequency}$) is of the same order of magnitude as the discharge constant, the reading will be lower than the absolute peak value. Type 2 does, on the other hand, have the advantage that it does not react as hysterically to noise pulses etc. as type 1.



Peak, type 2, ved lave frekvenser

Ved et sinusignal på 20 Hz vil type 2 peak detektoren vise en værdi, der ligger ca. 5 % under den sande peak værdi.

Ved højere frekvenser vil afvigelsen blive mindre, f.eks. ved 1 kHz er den mindre end 0,1 %.

Det siger sig selv, at peak detektoren bruges, når man ønsker at finde spidsværdien i et signal.

En peak måling kan sjældent erstatte en RMS- eller AVG måling, men vil ofte være et værdifuldt supplement til enten RMS- eller AVG målingen.

Peak, type 2, at low frequencies

For a sinusoidal signal of 20 Hz, the type 2 peak detector will show a value which is about 5 % below the true peak value.

At higher frequencies, the deviation will be less, e.g. at 1 kHz it is less than 0.1 %.

It goes without saying that the peak detector should be used when it is necessary to find the peak value of a signal.

A peak measurement can rarely replace an RMS or AVG measurement, but will often be a valuable supplement to either the RMS or the AVG measurement.

KURVEFORMER

For at illustrere nogle af de mange begreber og definitioner, er der valgt at vise en række eksempler på nogle typiske forekomne kurveformer.

Eksemplerne er vist både som DC og AC kobled. Her er det selvfølgelig de AC kobled signaler, der har størst interesse, men det er også en fordel at kunne se, hvad forskellen mellem AC- og DC kobling betyder.

Resultaterne for »sinus burst« og »pulstog« er vist som en funktion af »duty cyclen« ($D = t'/T$), og som alle de øvrige, er resultaterne vist for DC-peak værdien 1 volt.

Har man et aktuelt eksempel med en anden DC-peak værdi, ganges resultaterne selvfølgelig blot med denne værdi.

For »hvid støj« er beregningen mere kompliceret, og vist i Appendix 1.

Men som en rettesnor kan en peakværdi på ca. 3-4 bruges.

For at vise de principielle beregninger, er eksemplet med pulstog vist i Appendix 3.

CURVE FORMS

To illustrate some of the many terms and definitions we have chosen to show a number of examples of typical curve forms.

The example are shown for both DC and AC signals. It is of course the AC signals which are of the greatest interest here, but it is also an advantage to see what the difference between AC and DC connection means.

The results for sinusoidal burst and pulse train are shown as a function of the duty cycle ($D = t'/T$), and as for all the others, the results shown for the DC peak value are 1 volt.

In the case of an actual example with another DC peak value, the results should simply be multiplied by this value.

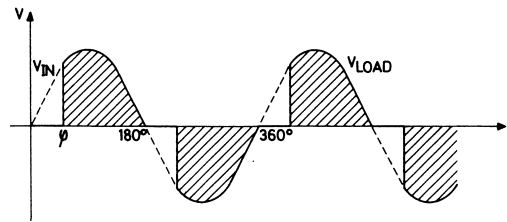
For "white noise" the calculation is more complicated and is shown in Appendix 1.

However, a peak value of approx. 3-4 can be used as a guide.

To show the principal calculations, the example with the pulse train is shown in Appendix 3.

EKSEMPEL 1 (SCR/TRIAC)

En af de kurveformer, der kan give målemæssige problemer, er det signal, der fremkommer, når en thyristor eller triac bruges til fasekontrol:



Fasekontrol med triac

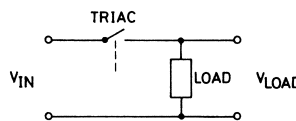
Kurven er tegnet for en ideel triac ($V_{ON} = 0$):

EXAMPLE 1 (SCR/TRIAC)

One of the curve forms which can cause measuring problems is the signal which occurs when a thyristor or triac is used for phase control:

Phase control with a triac

The curve has been drawn for an ideal triac ($V_{ON} = 0$):



I tabellen (side 12) er der lavet beregninger for V_{LOAD} for forskellige værdier af φ (0-180°). $V_{IN} = 220 \text{ V}_{RMS}$, er brugt i alle beregninger, og de matematiske beregninger er vist i Appendix 2.

Kolonne 1 angiver fasevinklen φ , hvor triac'en trigges, og kolonne 2 viser RMS spændingen over belastningen »LOAD«. Ofte benyttes en fasekontrol til at kontrollere den afsatte effekt i belastningen. Kolonne 3 viser den afsatte effekt som funktion af φ , med $\varphi = 0$ sat til 100%.

Måles V_{LOAD} med et middelværdivisende instrument (RMS sinus kalibreret) fås de i kolonne 4 angivne værdier, og kolonne 5 angiver, hvor stor afvigelsen er i 5 i forhold til den sande RMS værdi.

Kolonne 6 og 7 angiver PEAK værdien og crest faktoren. Bemærk, at CF når ganske høje værdier, når φ bliver større end ca. 90°. Og man skal være opmærksom på, at måleudstyrets max. input ikke overskrides (Full Scale værdi x max. tilladt CF).

In the table (page 12), calculations have been made for V_{LOAD} for various values of φ (0-180°).

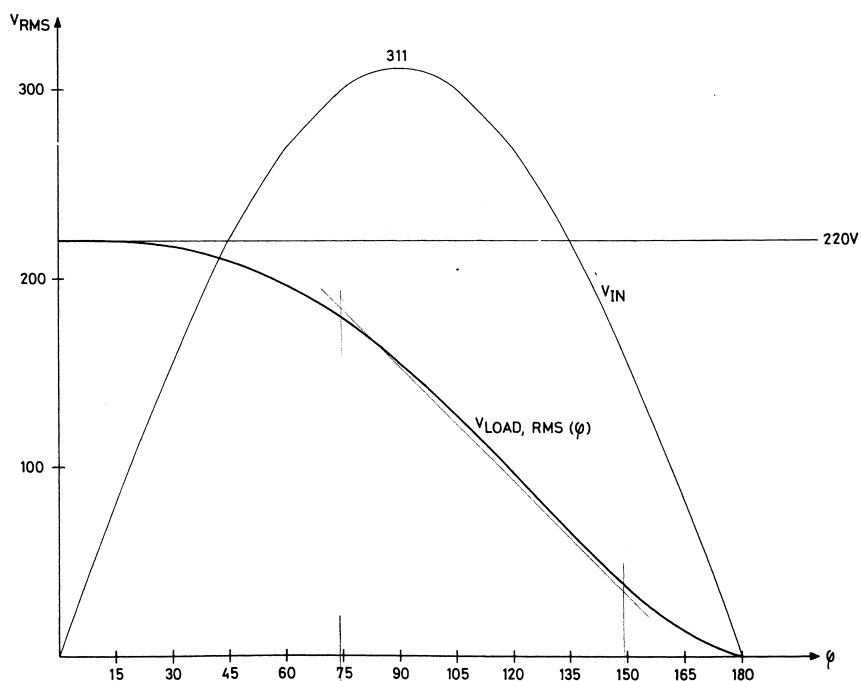
$V_{IN} = 220 \text{ V}_{RMS}$ has been used in all calculations, and the mathematical calculations are shown in Appendix 2.

Column 1 gives the phase angle at which the triac is triggered and column 2 shows the RMS value over the 'LOAD'. A phase control is often used to control the dissipated power in the load. Column 3 shows the dissipated power as a function of φ , with $\varphi = 0$ set at 100%.

If V_{LOAD} is measured with a mean value indication instrument (RMS-sine calibrated) the values contained in column 4 are obtained, and column 5 gives the size of the deviation in 4 from the true RMS value.

Column 6 and 7 give the PEAK value and the crest factor. It should be noted that C.F. reaches quite high values when φ is greater than about 90°. Care must be taken that the maximum input of the measuring equipment is not exceeded (full scale value x maximum permitted C.F.).

(+180°)	V _{RMS} (220 V)	Relative power %	V _{AVG} SIN-RMS Calibrated	% Error	V _{PEAK}	C.F.
0	220.0	100.0	220.0	0	311.1	1.41
15	219.6	99.6	216.2	-1.5	311.1	1.42
30	216.8	97.1	205.3	-5.3	311.1	1.44
45	209.8	90.9	187.8	-10.5	311.1	1.48
60	197.3	80.4	165.0	-16.4	311.1	1.58
75	179.3	66.3	138.5	-22.7	311.1	1.74
90	155.6	50.0	110.0	-29.3	311.1	2.00
105	127.7	33.7	81.5	-36.2	300.5	2.35
120	97.3	19.6	55.0	-43.5	269.4	2.77
135	66.3	9.1	32.2	-51.4	220.0	3.32
150	37.4	2.9	14.7	-60.6	155.6	4.16
165	13.5	0.4	3.7	-72.2	80.5	5.96
180	0	0	0	-	0	-
(179)	0.23	0.0001	0.02	-92.8	5.43	23.6



På kurven er $V_{LOAD, RMS}$ indtegnet som en funktion af ϕ . Det bemærkes, at det er en uliniær funktion, dog er forløbet mellem ca. 60 og 130° nogenlunde linier.

On the curve $V_{LOAD, RMS}$ is drawn as a function of ϕ . It should be noted that it is a nonlinear function, though the progression between 60 and 130° is fairly linear.

BRUG AF dB

Ofte vælges at udtrykke AC spændinger i dB (decibel). En dB angivelse er *altid* i forhold til en referenceværdi:

$$\text{dB} = 20 \times \log V/V_{\text{REF}}$$

I princippet kan V_{REF} vælges til en hvilken som helst værdi, dog har man valgt at lave en række »standard dB'er«:

$$\text{dBV} = 20 \times \log V/1.000$$

$$\text{dBm} = 20 \times \log V/0.775$$

De 0.775 V svarer til en afsat effekt på 1 mW i en impedans på 600 Ohm.

Hvis V_1 er ref for dB1 og V_2 for dB2, er sammenhængen mellem dB1 og dB2:

$$\text{dB2} = \text{dB1} + 20 \times \log V_1/V_2$$

For dBV og dBm giver dette:

$$\text{dBm} = \text{dBV} + 2.22$$

dB bruges også ved effektmålinger. Også her er der altid en referenceværdi:

$$\text{dB} = 10 \times \log P/P_{\text{REF}}$$

Indsættes $P = V^2/R$ i formelen fås:

$$\begin{aligned} \text{dB} &= 10 \times \log P/P_{\text{REF}} \\ &= 10 \times \log (V^2/R)/(V_{\text{REF}}^2/R) \\ &= 10 \times \log \left(\frac{V}{V_{\text{REF}}} \right)^2 \\ &= 20 \times \log V/V_{\text{REF}} \end{aligned}$$

d.v.s. der frit kan vælges mellem at udregne dB værdien ud fra spændingen eller effekten.

USE OF dB

AC voltages are often expressed in dB (decibels). A dB indication is *always* in relation to a reference value:

$$\text{dB} = 20 \times \log V/V_{\text{REF}}$$

In principle V_{REF} can be set at any value whatsoever, but a number of "standard dB's" have been fixed:

$$\text{dBV} = 20 \times \log V/1.000$$

$$\text{dBm} = 20 \times \log V/0.775$$

The 0.775 V corresponds to a dissipated power of 1 mW in an impedance of 600 Ω .

If V_1 is the reference for dB1 and V_2 the reference for dB2, the correlation between dB1 and dB2 is as follows:

$$\text{dB2} = \text{dB1} + 20 \times \log V_1/V_2$$

For dBV and dBm this produces:

$$\text{dBm} = \text{dBV} + 2.22$$

dB are also used for power measurements. Here too it always has a reference value:

$$\text{dB} = 10 \times \log P/P_{\text{REF}}$$

Inserting $P = V^2/R$ in the equation produces:

$$\begin{aligned} \text{dB} &= 10 \times \log P/P_{\text{REF}} \\ &= 10 \times \log (V^2/R)/(V_{\text{REF}}^2/R) \\ &= 10 \times \log \left(\frac{V}{V_{\text{REF}}} \right)^2 \\ &= 20 \times \log V/V_{\text{REF}} \end{aligned}$$

i.e. it is possible to choose freely between calculating the dB value on the basis of the voltage or of the power.

APPENDIX 1

Normalfordelt støj

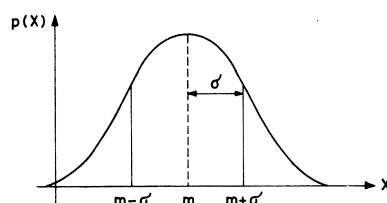
Normalfordelt støj kaldes også for hvid- eller gaussisk støj.

Rent frekvensmæssigt er hvid støj kendetegnet ved at alle frekvenser er repræsenteret.

Til beskrivelse af hvid støj anvendes sandsynlighedsfunktionen for normalfordelingen:

$$p(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-(x-m)^2/2\sigma^2}$$

m – middeværdi
σ – standard
afvigelsen



m – mean value
σ – standard
deviation

Elektrisk støj stammer fra elektronbevægelser i alle komponenter m.v.

Da støjen er en sum af næsten uendelig mange enkelte bidrag, hvor det enkelte bidrag ikke har nogen indflydelse på resultatet, er resultatet en normalfordeling.

En sådan fordelingsfunktion siger intet om støjsignalet, hvis man betragter det momentant, men det siger noget om, hvordan signalet sandsynligvis vil se ud. F.eks. at der er størst sandsynlighed for at ligge omkring middelværdien m.

For et AC koblet støjsignal er middelværdien 0.

RMS værdien er pr. definition lig med σ, idet σ udregnes som:

Formel A1
$$\sigma = \sqrt{\frac{1}{n} \sum_{i=1}^n (x_i - m)^2}$$

Denne formel svarer nøjagtig til formlen for RMS udregning (Formel 3), når m = 0.

I henhold til formel 6 beregnes den numeriske middelværdi som:

$$AVG = \frac{1}{T} \int_0^T [v(t)] dt$$

Denne formel er for tidsfunktion.

Har man istedet en sandsynlighedsfunktion, p(x), bliver udregningen:

APPENDIX 1

Normal Distribution Noise

Normal distribution noise is also called white or Gaussian distribution noise.

Purely from a frequency point of view, white noise is characterized by all frequencies being represented in it.

To describe white noise, the probability function for normal distribution is used:

Electrical noise is caused by electron movements in all components etc. As noise is the sum total of a virtually infinite number of individual contributions, with the individual contribution not having any influence on the result, the result is a normal distribution. Such a distribution function does not say anything about the noise signal, if it is considered momentarily, but it does say something about how the signal will probably look. E.g. that there is the greatest probability of it having the mean value m.

For an AC noise signal, the mean value is 0.

The RMS value is by definition equal to σ, with σ being calculated as:

Equation A1
$$\sigma = \sqrt{\frac{1}{n} \sum_{i=1}^n (x_i - m)^2}$$

This equation corresponds exactly to the equation for RMS calculation (Equation 3), when m = 0.

According to equation 6, the numeric mean value is calculated as:

$$AVG = \frac{1}{T} \int_0^T [v(t)] dt$$

This equation is for a time function:

If a probability function, p(x), is used instead, the calculation is as follows:

Udregninger:

Calculation:

$$\begin{aligned}
 \text{AVG} &= \int_{-\infty}^{\infty} |x| \cdot p \cdot (x) dx \\
 &= 2 \int_0^{\infty} x \left(\frac{1}{\sqrt{2\pi} \cdot \sigma} \cdot e^{-x^2/2\sigma^2} \right) dx \quad (m = 0) \\
 &= \frac{2}{\sqrt{2\pi} \cdot \sigma} \int_0^{\infty} (-1/2) \cdot e^{-x^2/2\sigma^2} \cdot d(-x^2) \\
 &= \frac{-1}{\sqrt{2\pi} \cdot \sigma} \int_0^{\infty} 2\sigma^2 \cdot e^{-x^2/2\sigma^2} \cdot d(-x^2/\sigma^2) \\
 &= \frac{-2\sigma}{\sqrt{2\pi}} \cdot \left[e^{-x^2/2\sigma^2} \right]_0^{\infty} \\
 &= \frac{2\sigma}{\sqrt{2\pi}} \cdot (0-1) \cdot \sqrt{\frac{2}{\pi}} \cdot \sigma = 0,798 \cdot \sigma
 \end{aligned}$$

Teoretisk set er peak værdien for hvid støj uendelig stor. Men da støjen følger en kendt sandsynlighedsfunktion er det muligt at sige noget om sandsynligheden for forskellige peak værdier. Sandsynligheden for at få en spids, der er numerisk større end 2 gange RMS værdien (= σ) er ca. 5%.

Seen theoretically, the peak value for white noise is infinitely large. But as the noise follows a known probability function, it is possible to say something about the probability of various peak values. The probability of obtaining a peak which is numerically greater than twice the RMS value (= ζ) is approx. 5%.

Sagt på en anden måde vil støjsignalet være numerisk større end 2 gange RMS værdien i ca. 5% af tiden.

To put it another way, the noise signal will be numerically greater than twice the RMS value approx. 5% of the time.

CF $\left(\frac{\text{PEAK}}{\text{RMS}} \right)$	1.5	2.0	2.5	3.0	3.3	4.0	5.0
Sandsynlighed/ Probability	13 %	4.6 %	1.2 %	0.26 %	0.005 %	0.0006 %	0.6 ppm

I praksis vil man således yderst sjældent komme ud for peak signaler, der er større end 3-4 gange RMS værdien.

In practice it is therefore very rare for peak signals greater than 3-4 times the RMS value to be encountered.

De aller fleste AC voltmeter kan klare en CF på 3, så spidsværdierne i et støjsignal vil sjældent overstige det maksimale tilladte indgangsniveau.

By far the majority of voltmeters can manage a C.F. of 3, to the peak values in a noise signal will rarely exceed the maximum permitted input level.

Omkring fortolkning af støjmålinger skal der henvises til mere specialiseret litteratur. Bla. findes der DIN-og IEC normer for støjmålinger, m.h.t. frekvensvægtning, detektortyper og målebetingelser.

On the subject of noise measurement interpretation, reference should be made to more specialized literature. There are, among other sources, DIN and IEC standards for noise measurements, which refer to frequency weighting, types and measuring conditions.

APPENDIX 2

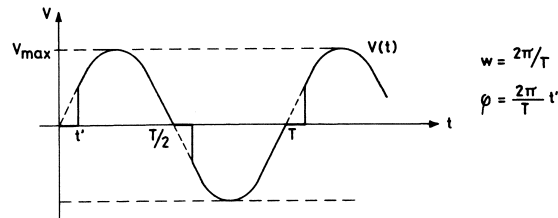
Beregning vedr. eksempel 1

Fasekontrol med TRIAC:

APPENDIX 2

Calculations for example 1

Phase control with TRIAC:



$$\begin{aligned} \text{AVG} &= \frac{1}{T} \int_0^T |V(t)| dt = V_{\max} \cdot \frac{2}{T} \int_{t'}^{T/2} \sin \cdot \omega t \cdot dt \\ &= V_{\max} \frac{2}{T} \left[-\frac{T}{2\pi} \cdot \cos \frac{2\pi}{T} \cdot t \right]_{t'}^{T/2} = \frac{V_{\max}}{\pi} \left(-1 - \cos \cdot \frac{2\pi}{T} \cdot t' \right) \end{aligned}$$

$$= \frac{V_{\max}}{\pi} (\cos \varphi + 1)$$

$$\text{RMS} = \sqrt{\frac{1}{T} \int_0^T [v(t)]^2 dt} = \sqrt{\frac{2 \cdot V_{\max}^2}{T} \int_{t'}^{T/2} \sin^2 \cdot \omega t \cdot dt}$$

$$= \sqrt{\frac{2 \cdot V_{\max}^2}{T} \cdot \frac{1}{\omega} \cdot \left[\frac{\omega t}{2} - \frac{\sin \cdot 2 \cdot \omega t}{4} \right]_{t'}^{T/2}}$$

$$= \sqrt{\frac{2 \cdot V_{\max}^2}{T} \cdot \frac{T}{2\pi} \cdot \left[\frac{2\pi \cdot t}{T \cdot 2} - \frac{\sin \cdot \frac{4\pi}{T} \cdot t}{4} \right]_{t'}^{T/2}}$$

$$= \sqrt{\frac{V_{\max}^2}{\pi} \left(\frac{\pi}{2} - 0 - \left(\frac{\varphi}{2} - \frac{\sin 2\varphi}{4} \right) \right)}$$

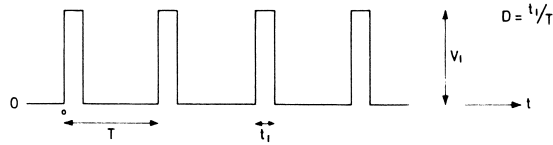
$$= V_{\max} \sqrt{\frac{1}{2} - \frac{\varphi}{2\pi} + \frac{\sin 2\varphi}{4\pi}}$$

$$\begin{aligned} \text{PEAK} &= V_{\max}, & 0^\circ \leq \varphi \leq 90^\circ \\ &= V_{\max} \cdot \sin \varphi, & 90^\circ \leq \varphi \leq 180^\circ \end{aligned}$$

APPENDIX 3

Beregning for pulstog

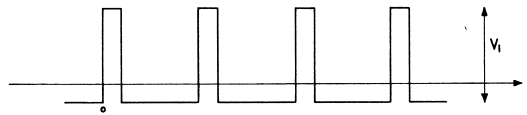
DC



$$\begin{aligned} \text{DC} &= \frac{1}{T} \int_0^T V \cdot (t) \cdot dt = \frac{1}{T} \int_0^{t_1} V_1 \cdot dt = V_1 \cdot t_1/T \\ &= V_1 \cdot D \end{aligned}$$

$$\text{PEAK}_{\text{DC}} = V_1$$

AC



$$\begin{aligned} \text{RMS} &= \sqrt{\frac{1}{T} \int_0^T [V \cdot (t)]^2 \cdot dt} = \\ &= \sqrt{\frac{1}{T} \left(\int_0^{t_1} (V_1 - V_1 \cdot D)^2 dt + \int_{t_1}^T (-V_1 \cdot D)^2 dt \right)} \\ &= V_1 \sqrt{\frac{1}{T} \left(\int_0^{t_1} (1-D)^2 dt \int_{t_1}^T D^2 dt \right)} \\ &= V_1 \sqrt{\frac{1}{T} \left([1 + D^2 - 2D] t_1 + [D^2 T - D^2 t_1] \right)} \\ &= V_1 \sqrt{\frac{1}{T} (t_1 - 2D t_1 + D^2 T)} \\ &= V_1 \sqrt{D - 2D^2 + D^2} = V_1 \sqrt{D - D^2} \end{aligned}$$

APPENDIX 3

Calculations for pulse train

$$\begin{aligned}
 \text{AVG} &= \frac{1}{T} \int_0^T |V(t)| dt \\
 &= \frac{1}{T} \left(\int_0^{t_1} (V_1 - (V_1 \cdot D)) dt + \int_{t_1}^T (V_1 \cdot D) dt \right) \\
 &= \frac{1}{T} (V_1 (1-D) \cdot t_1 + V_1 \cdot D \cdot T - V_1 \cdot D \cdot t_1) \\
 &= V_1 \cdot D (1-D) + V_1 \cdot D - V_1 \cdot D^2 = 2 V_1 D - 2 V_1 \cdot D^2 \\
 &= 2 V_1 (D - D^2)
 \end{aligned}$$

$$\begin{aligned}
 \text{PEAK} &= D < 1/2 \quad \text{PEAK} = 1 - D \\
 &= D > 1/2 \quad \text{PEAK} = D
 \end{aligned}$$

$$\begin{aligned}
 \text{RMS}_{\text{DC+AC}} &= \sqrt{AC^2 + DC^2} \\
 &= \sqrt{[V_1 \sqrt{D - D^2}]^2 + [V_1 \cdot D]^2} \\
 &= V_1 \sqrt{D - D^2 + D^2} = V_1 \sqrt{D}
 \end{aligned}$$

$$\text{CF}_{\text{AC}} = \frac{V_{\text{PEAK}}}{V_{\text{RMS}}} = \frac{1-D}{\sqrt{D-D^2}} \quad (D < 1/2)$$

$$\text{CF}_{\text{DC}} = \frac{V_{\text{PEAK}}}{V_{\text{RMS}}} = \frac{1}{\sqrt{D}}$$

Bemærk at CF_{AC} og CF_{DC} er forskellige/
 Notice that CF_{AC} and CF_{DC} are different

$$\begin{aligned}
 D = 1/3 : \text{CF}_{\text{AC}} &= 1.31 \\
 \text{CF}_{\text{DC}} &= 1.73
 \end{aligned}$$

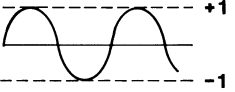
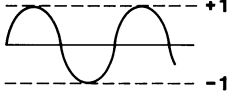
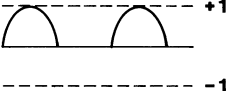
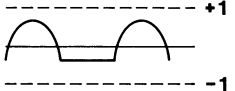
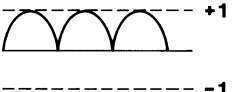
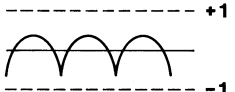
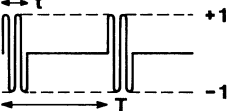
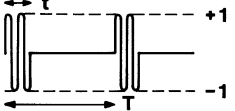
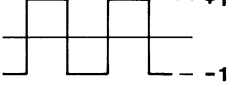
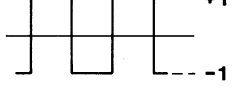

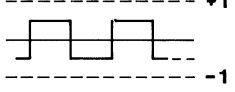
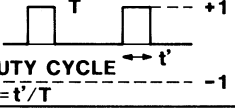

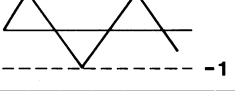
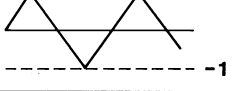

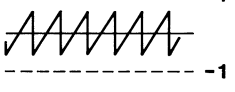


$$\begin{aligned}
 D = 1/10 : \text{CF}_{\text{AC}} &= 3.00 \\
 \text{CF}_{\text{DC}} &= 3.16
 \end{aligned}$$

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	DC KOBLET			AC KOBLET								RMS DC+AC
	SIGNAL	DC	PEAK	SIGNAL	RMS	AVG	PEAK	CF	FF	AVG RMS SIN CAL	FEJL I %	
SINUS		0	1,000		0,707	0,637	1,000	1,41	1,11	0,707	0	0,707
ENSRET-TET SINUS		0,318	1,000		0,386	0,351	0,682	1,77	1,10	0,390	+1,1	0,500
DOBBELT ENSRET-TET SINUS		0,637	1,000		0,308	0,268	0,637	2,07	1,15	0,298	-3,2	0,707
SINUS BURST		0	1,000		$\sqrt{\frac{t'}{2T}}$	$\frac{2t'}{\pi \cdot T}$	1,000	$\sqrt{\frac{t'}{2T}}$	$\frac{\pi}{2} \sqrt{\frac{T}{2t'}}$	$\frac{2,22t'}{\pi \cdot T}$	$\left \sqrt{\frac{t'}{T}} - 1 \right 100$	$\sqrt{\frac{t'}{2T}}$
FIRKANT		0	1,000		1,000	1,000	1,000	1,00	1,00	1,11	+11	1,000
ENSRET-TET FIRKANT		0,500	1,000		0,500	0,500	0,500	1,00	1,00	1,11	+11	0,707
PULSTOG DUTY CYCLE $D = t'/T$		D	1,000		$\sqrt{D-D^2}$	$2(D-D^2)$	$\frac{(D-1/2)}{D}$	$\frac{1-D}{\sqrt{D-D^2}}$	$\frac{1}{2\sqrt{D-D^2}}$	$2,22(D-D^2)$	$100 \cdot (2,22 \cdot \sqrt{D-D^2} - 1)$	\sqrt{D}
TREKANT		0	1,000		0,577	0,500	1,000	1,73	1,16	0,520	-9,8	0,577
SAVTAND		0,500	1,000		0,289	0,250	0,500	1,73	1,16	0,278	-3,8	0,577
STØJ		0	*		1,000	0,798	*	*	1,25	0,887	-11,3	1,000