N°CA860101

LEM SA LIAISONS ÉLECTRONIQUES
MÉCANIQUES S.A. GENÈVE

LEM MODULE

Current and Voltage Sensors

Description and Applications

SUMMARY

JANUARY 1986

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LEM MODULE

1) DEFINITION

The LEM MODULE is a current sensor using a Hall generator, which operates at zero magnetic flux (Feedback System)

Two principal properties - the LEM MODULE is capable:

- of measuring any current (AC, DC, Pulsed...) in a large range of Amplitude and frequencies
- of measuring these currents with galvanic isolation.

2) SYSTEM CONCEPT

The magnetic flux created by the current to measure, is balanced through a secondary coil with a Hall effect sensor, associated with an electronic circuit.

The secondary current (compensation current) is an exact duplicate at any time of the primary current (reduced by the number of turns of the compensating coil).

3) MAIN ADVANTAGES

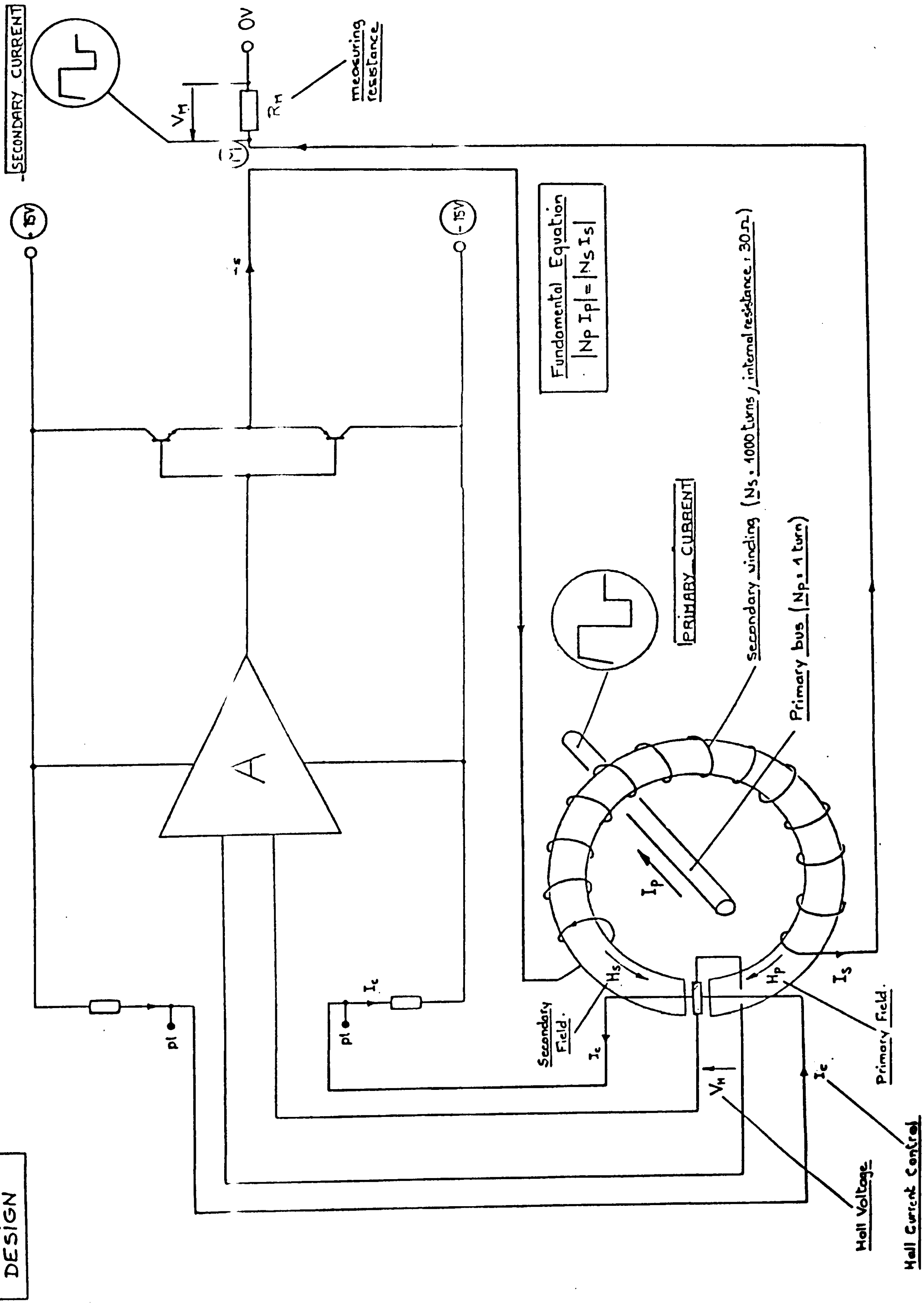
- it is possible to measure any current (e.g. transient peaks)
- complete electrical isolation between primary and secondary circuit
- high precision: accuracy better than 1 %
- linearity : better than 0.1 %
- very fast response: delay time inf. to 1 µs
- large band width: 100 kHz and dI/dt accurately followed sup. to 50 A/µs
- large scale of measure and overload capacity

4) DESCRIPTION

The LEM MODULE is composed of:

- a primary circuit
- a magnetic circuit with a Hall sensor located in the air gap
- a secondary winding
- an electronic circuit (secondary current generator)

PRINCIPLE DESIGN



5) BRIEF ANALYSIS AND CALCULATION

5.1) OVERVIEW OF THE HALL EFFECT

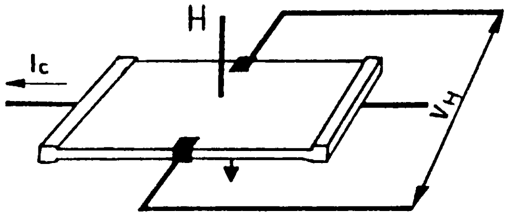
$$\boxed{\vec{V}_H = K \times |\vec{H} \times \vec{I}_c|}$$

V_H = output Hall voltage

K = Hall constant (depends on the semiconductor material)

H = magnetic field created by the current to be measured

I_c = control current



In the case of the LEM MODULE, I_c is a constant current so, the Hall Voltage is only proportional to the magnetic field H.

Employed materials for Hall Generators : In, Sb (Indium, Antimonium)

Ga, As (Gallium, Arsenium)

N.B. For the Hall Generator presently used : I_c = 10 mA and sensitivity

V_H = 10 mV for H = 4 mT.

5.2) FUNDAMENTAL RELATION (THEORETICALLY)

$\boxed{N_p I_p + N_s I_s = 0}$ (the sensor operates at zero magnetic flux)

$\boxed{|N_p I_p| = |N_s I_s|}$ (in ampere-turns)

Np = number of primary turns
Ip = primary current
Ns = number of secondary turns
Is = secondary current

The primary ampere-turns are equal to the secondary ampere-turns. In other words, the primary magnetic field (due to Np Ip) is exactly compensated by the secondary magnetic field (due to Ns Is).

For instance: with the model LT 100-P, the secondary winding possesses 1000 turns (Ns). So a primary field due to a current (Ip) of 1 A flowing through 1 wire, will be compensated by a secondary field due to a current (Is) of 1 mA.

5.3) ACCURACY

In fact (Ns Is) is not exactly identical to (Np Ip); this is due to the following factors:

- The offset current when Ip = 0 (DC value)

  due to | the op. amplifier offset.
  | the Hall generator offset.

The offset adjustment, carried out with appropriated LEM equipment, limits the offset current at 0.1 A.t.

- Accidental distortion of the offset value:

  Residual induction of the magnetic circuit can induce a permanent current (DC) added to the real current. For instance, if the magnetic circuit has been magnetized (e.g.: when a high DC current flows through the primary circuit while the sensor is not supplied or its measuring circuit is open.)

  N.B.: After that, it is always possible to demagnetize (with a decreasing primary AC current, the measuring circuit not being "supplied") in order to suppress the magnetic residual.

  In any case, with the magnetic material, presently employed, this error is limited at 0.5 A.t.

- Offset drift with temperature

  By a special selection of the op. amplifiers and the Hall generators, this drift gives an error (DC), expressed in comparison with the nominal current, inferior to 10-4 x I_N / C°.

  For example with LT 100-P:

  Ip nominal = 100 A
  if ΔT = 50°C the drift with temperature is :
  10-4 x 100 A x 50 °C = 0.5 A for Ip = 100 A
  so for the secondary, this error becomes (turn ratio 1/1000) :
  0.5 mA for Is = 100 mA

  This offset drift might also be expressed in ampere-turns:
  in that case the drift with temperature is lower than : 0.01 A.t/°C
  so for this example it becomes : 0.01 A.t x 50 °C = 0.5 A.t maximum.

Remark: Errors described as above are constant errors, therefore they have to be taken into consideration for measuring DC currents. They are independent of the current level to be measured - this constant total error is 1 A.t maximum.

- Linearity

The zero flux method allows a linearity better than 0.1 % of the nominal current.

- Dynamic performances

1. Delay Time and dI/dt Response

The high sensitivity makes the LEM MODULE's response better than 1 µs.

The dI/dt accurately followed is usually 50 A/µs, even up to 100 A/µs for certain models.

This depends on the primary to secondary magnetic coupling.
For example:

Dynamic performances (response time and di/dt) are optimum with a single bar filling perfectly the primary hole.

2. Frequency Operation

The electronic circuit exactly balances up to 3 to 5 KHz frequencies (typical error : 0.5 %)

For higher frequencies the compensation current is also supplied by "transformer effect" (magnetic coupling).

The total compensation is rather good, up to 100 KHz.

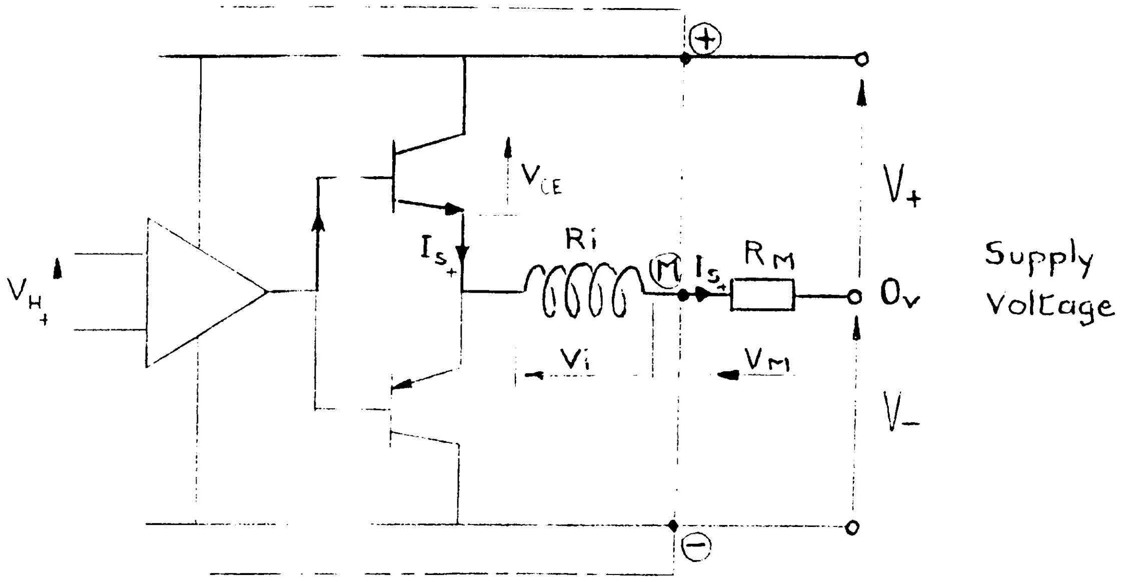
- TO SUM UP THE CHARACTERISTICS

THE LEM MODULE IS CAPABLE OF SENSING "HIGH CURRENTS" (DC, AC, MIXED, PULSED..) WITH A TOTAL ACCURACY BETTER THAN 1 %

5.4) MEASURING RANGE

Depends on the capability of the secondary current generator to supply the compensation current. (Is)

The electronic circuit can be simplified as follows :



Determination of the measuring range:

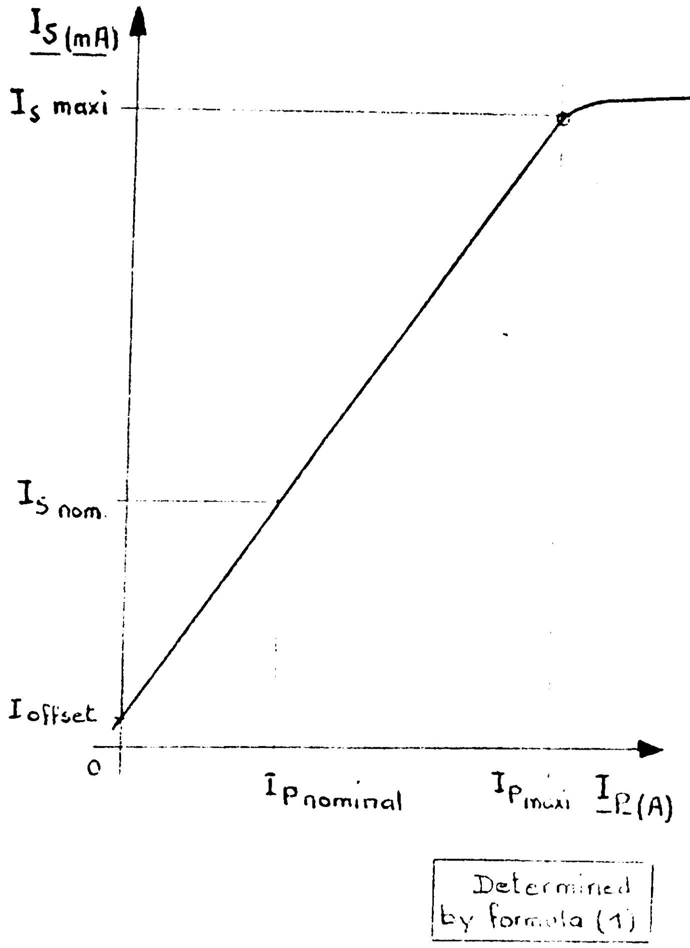
I_s maximum depends on the following factors:

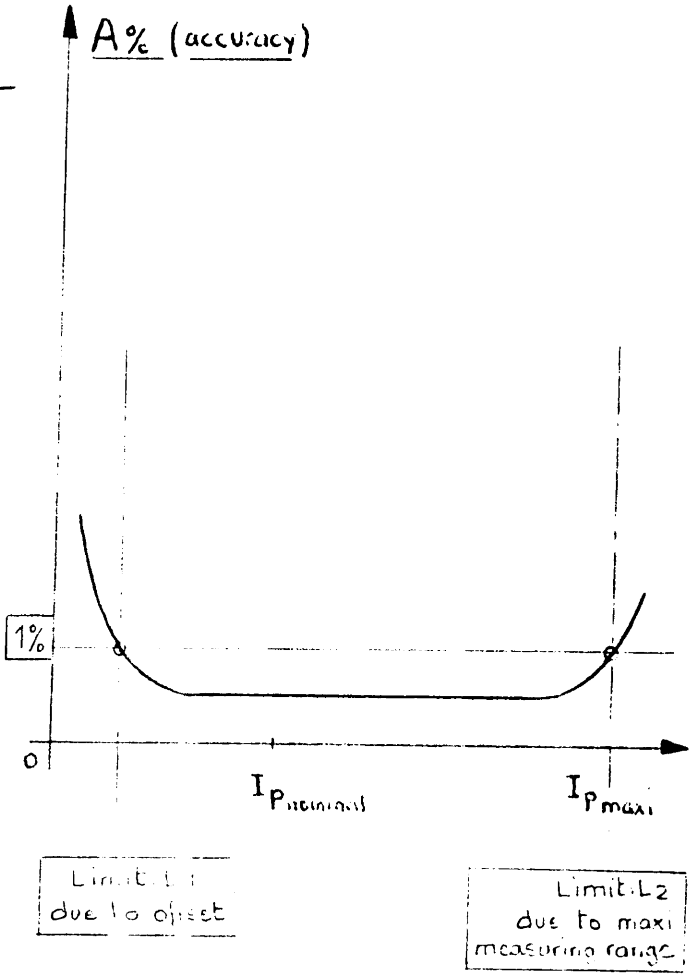
- available supply voltage: V
- internal voltage drop due to: Ri x Is = Vi
- external voltage drop due to: Rm x Is = Vm (measuring voltage)
- saturation voltage of the output transistors: Vcesat

$$\boxed{I_s \text{ maximum} = \frac{V - V_{CE\,sat}}{R_i + R_m}} \quad (1)$$

Remark: To determine the measuring range, our data sheets also take into consideration the maximum allowed thermal power on components and materials.

5.5) GRAPHIC REPRESENTATION





Remark: Because of the saturation of the transistors and the magnetic circuit, the LEM MODULE is able to support without damage overload currents beyond the normal range of operation.

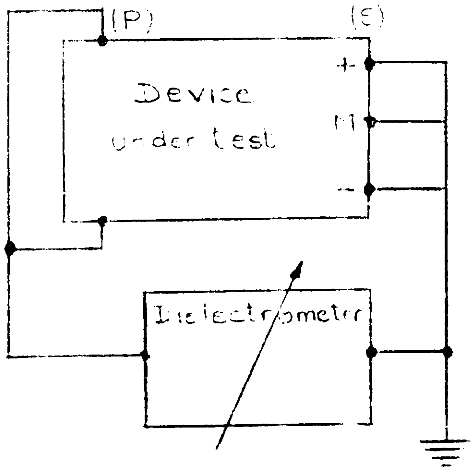
6) POWER SUPPLY CONSUMPTION

The power supplies have to deliver the internal consumption (no load current : op. Amplifier, Hall sensor...) and the maximum compensation current during measurement.

7) INSULATION TEST VOLTAGE

$\boxed{\text{V test (rms) = 2.U operating + 1000V}}$ (unless other specifications required)

V test is applied between Primary and Secondary circuit connected to the ground.



e.g. : test voltages usually carried out.
3kV - 6kV - 12kV rms/50Hz/1 min.

N.B. : on certain models higher insulations have been realized :
20 kV up to 50 kV rms/50Hz/1 min.

8) IMMUNITY TO EXTERNAL MAGNETIC FIELDS

For the majority of applications, immunity against external fields is sufficient, the magnetic circuit is designed in order to get no error higher than 0.5 % when a magnetic field is created by a current of 2 x Ip nominal into a conductor set between 5 and 10 cm from the LEM MODULE.

However, for applications where higher magnetic fields disturb the MODULE, the following solutions have to be used:

- orient the MODULE so that the external magnetic field does not disturb the Hall element. This solution is the simplest, but often difficult to achieve because of the mounting problems in the equipment.

- increase the section of the magnetic circuit or use an external magnetic shield.

- finally, use a MODULE with 2 or several compensation circuits which cancel the effect of the external field. This is a more expensive solution but very effective.

9) TESTS CARRIED-OUT ON THE LEM MODULE

- List of the main type tests usually done on a module.

- 3 kinds of tests are made:

  - electrical tests
  - climatical tests
  - mechanical tests

a) Electrical Tests

All the characteristics defined in the data sheet are checked at ambient temperature.

b) Climate tests

The main electrical characteristics are checked in the following tests.

- Cold operating temperature
- Dry heat temperature
- Damp heat operating
- Composite (hot cold) temperature

c) Mechanical tests

- Sinusoidal vibrations
- Shock

10) USUAL NORMS

Usually the "International Electrical Commission" Rules (I.E.C.) are employed for the LEM MODULE definition.

For example:

- Insulation Tests: IEC 112
- Security Rules: IEC 51
- Enclosure Protection: IEC 529
- Basic Environmental Testing Procedures: IEC 68
- Rules for electronic equipment in railroads IEC 571

11) SUMMARY AND OTHER ADVANTAGES OF THE LEM MODULE

The LEM MODULE is relatively insensitive to environmental conditions and can be used in many applications.

In addition to the advantages described on the first page:

- The LEM MODULE is easy to mount. It doesn't bring any loss in the line, because the primary resistance and inductance which are introduced into the power circuit of the equipment, are negligible.

  - The LEM MODULE is protected against overloads in the primary circuit (beyond the normal operating range) because the primary energy transmitted to the secondary circuit is limited by:

    - the saturation of the output transistors.
    - the magnetic saturation of the magnetic core.

    Overload currents of 20 x I nominal are supported by the LEM MODULE without damages.

  - The primary to secondary "capacity" of the LEM MODULE is slight, so the influence of variations of common mode voltages is generally negligible in most applications, but sometimes the LEM MODULE possesses its own screen (note "E") when high potential variations are applied (several KV/µsec.)

    This is why the LEM MODULE is interesting to use, even when no insulation measurements are required.

  - The high sensitivity of the LEM MODULE allows you to discriminate a slight signal over a "high component part", for example AC milliamps over a DC component of several hundred Amperes.

    It is also possible to measure a differential current of several "high currents" flowing in opposition through the LEM MODULE's aperture, in order to monitor a system.

12) MAIN APPLICATIONS

- Speed Control Monitoring (AC, DC motors)
- Converters
- Safety Supplies
- Electrical Welding Equipment
- Automatic Robotic Systems
- Laboratories - Test Platforms
- Transportation