HIGH-PRECISION MEASURING TECHNIQUE FOR STRAIN GAGE TRANSDUCERS

Manfred Kreuzer

Head of Research and Development
Hottinger Baldwin Messtechnik
Im Tiefen See 45
D-64293 Darmstadt
Germany

ABSTRACT

The signals of strain gage transducers are very small. In consequence, error signals can even exceed the measuring signal amplitudes and therefore must be suppressed by sophisticated measuring circuits. The paper discusses the problems and solutions for high resolution, high stability and efficient suppression and damping of error signals and unwanted dynamic signals. It describes the absolute physical limits for the resolution of strain gage transducer signals and how carrier frequency technique can get very close to the boundary of theoretically achievable maximum resolution. Very high gain stability can be achieved with very precise inductive dividers as reference signal sources and with auto-calibration cycles. Realisations of the philosophy are shown for high-precision static measuring units and for universal broadband amplifier systems.

1 APPLICATION OF HIGH PRECISSION INSTRUMENTS

There are many applications that require high-precision measuring instruments.

The highest precision is requested by the National Institutes of Standard like the NIST in US or the PTB in Germany especially in the fields of force measurements and weighing systems.

All strain gage transducer manufacturers also need very stable, precise and reliable measuring instruments for calibration purposes in their production lines.

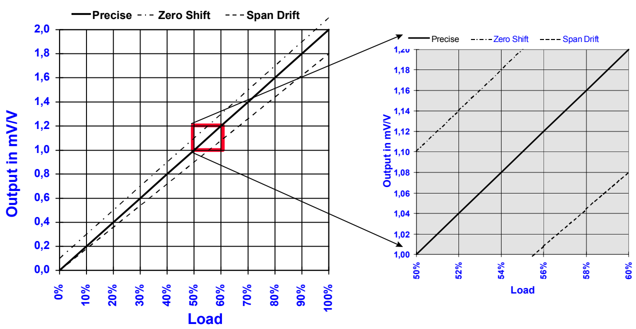


Fig. 1: High resolution demands high stability

But also common customers and users of strain gage measuring systems are increasingly interested in high-precision instruments. One simple reason is the search for measuring chains in which the errors depend on the transducers only and where the instrument errors can be neglected. An instrument can then be replaced by a new one in case of a breakdown without re-calibration.

A more important reason is the trend - supported very much by ISO9000 - to calibrate only the transducers without their usually connected electronic measuring systems. This demands interchangeability of different electronics to obtain the same results. But the basis of interchangeability is high precision of the measuring instruments. The transducer output signals in mV/V must be measured very exactly. Any loading of the transducer output has to be avoided. Zero balancing of the measuring chains may not be done by shunt-networks parallel to the transducers, it has to be done by a subtraction mechanism inside the instruments. But if this method is used the measuring instruments must provide very high stability also in tasks with only medium accuracy required, especially when high resolution is demanded.

Fig. 1 explains the reason for this dependency. If small signals must be recorded in sensitive ranges with high gain, zero balance-variations and span-drifts can generate very large measuring errors, because these errors are magnified by the high gain of the sensitive range.

2 DEFINITION OF PRECISION AND HIGH RESOLUTION

In the following this paper will discuss how instruments must be designed to achieve high resolution and high stability. It will show the physical limits of the achievable resolution and how close we can get to them by suppressing all the various other error signal sources. Of course the highest precision can be achieved in the field of static signal measurements. But the principle shown can also be applied to broad-band amplifiers. The best of the static measuring instruments are able to resolve and display a 2 mV/V strain gage transducer signal with 2.000.000 digital steps. They got the following specs:

Accuracy Class	0.0005 %	= 5 part per million
Resolution	2.000.000 d	
Linearity Error	<5 ppm	(part per million)
Zero Point Drift	<3 ppm / 10° F	
Span Drift	<3 ppm / 10° F	
Long-term Drift	<5 ppm / year	

The resolution of 2.000.000 d for the very small analogue signals of 2 mV/V is really remarkable. To get a feeling for this very high resolution: One out of 2.000.000 corresponds to one foot in the distance of Los Angeles to San Francisco or e.g. one second in a time period of three weeks. Considering what happens with the strain gages involved causes even more astonishment.

If a transducer uses strain gages with 3 mm grid length then their extension under nominal load is only 0.1% = 3µm. 1/2.000.000 of nominal load means that the gages extend only by 1.5 pm (Pico Meter). This is only 1% of the diameter of the smallest (not lightest) atom (Helium). So we are already in the subatomic range and therefore it is not surprising that noise voltages caused by temperature dependant movement of the atoms and electrons limit a further increase of signal resolution.

3 PHYSICAL LIMIT OF RESOLUTION

The generated noise level can be calculated by the well known formula:

$$V_{rms} = \sqrt{4 k \cdot T \cdot R \cdot B}$$

V_{rms}	=	Root Mean Square Noise Voltage
k	=	Boltzmann Constant (1.380662 · 10^{-23} J/K)
T	=	Absolute Temperature in K
R	=	Resistance in Ω
B	=	Bandwidth in Hz

V_{rms}	=	**2.4 nV (Noise Voltage of a 350 Ω Transducer; 1 Hz Bandwidth**
V_{rms}	<	**5.0 nV (Noise Voltage of Transducer and Amplifier, 350 Ω and 1Hz)**
V_{pp}	<	**20 nV ($V_{pp} = 4 * V_{rms}$; Definition: Standard Deviation σ = 2)**

The thermal noise voltage generated by the resistance of the transducers alone is the absolute physical limit for signal resolution. The noise voltage of a 350Ω transducer amounts to only 2.4 nV/sqr(Hz). With an excellent low-noise amplifier the total noise of the measuring chain (amplifier and electronic together) can be kept lower than twice the transducers noise voltage alone. So the total noise voltage levels which can be achieved are smaller than 5 nV/sqr(Hz).
Due to the fact we are not interested in the power of the noise voltage but in the span of generated uncertainty of the measurement we calculate the peak-to-peak voltage which is related by statistical laws. In the technical area the calculation with a standard deviation of σ = 2 is common. This results in $V_p = 2*V_{rms}$ and $V_{pp} = 4*V_{rms}$.
With the definition of σ = 2 the momentary voltage levels stay for 95.4% inside of the boundaries of $+-2*V_{rms}$ and exceed these boundaries only during 2.3% of the total measuring time to higher and during 2.3% of total measuring time to lower levels.
The peak-to-peak noise voltage is V_{pp} = 20 nV/sqr(Hz).
If a transducer is excited with 10V its output voltage at nominal load is 20 mV (2mV/V*10V). The measuring-to-noise voltage ratio is therefore 20 mV / 20 nV = 1.000.000 if the bandwidth is 1 Hz. Fig. 2 shows the maximum possible resolution for 5 V and 10 V excitation voltages as a function of bandwidth. To achieve 2.000.000 steps of resolution the transducer must be supplied with 10V and the bandwidth must be reduced to 0.25 Hz.
Noise voltages are not the only error signals. But they are the only ones we cannot get rid of completely. We only can reduce the bandwidth and lower the noise level.
According to the above formula we could also largely decrease the temperature T of the transducer and the amplifier towards the absolute zero point to lower the noise levels. But this cannot be applied in usual measuring environments. Reducing the transducer resistance R is also of no help because if constant excitation power is assumed the excitation voltage must be reduced equally and the signal-to-noise ratio will not change.

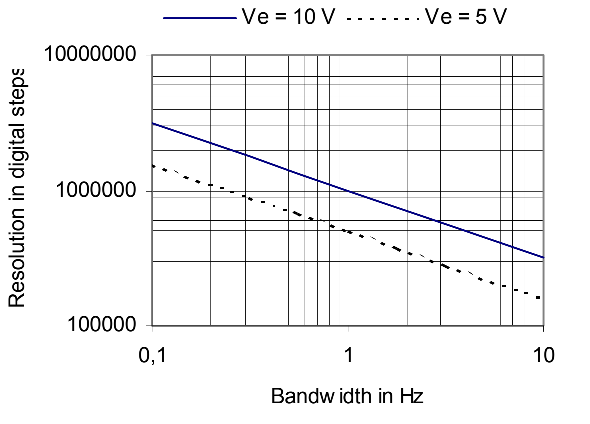


Fig. 2 Maximum resolution for 2 mV/V signals

4 CARRIER FREQUENCY TECHNIQUE

Other error signals are thermocouple voltages, amplifier offset drifts, power line interference and all sorts of high-frequency electromagnetic interference (EMI). A thermocouple of Copper/Constantan generates 42.5 µV/K. If a temperature difference of only 1K occurs during the measuring cycle this error signal is approximately 0.2% of the nominal transducer signal of 20 mV. The reliable resolution would shrink then extremely from 2.000.000d to only 470d.
A common amplifier drift of 1µV/K would reduce the resolution to 2.000 d if a change in ambient temperature of 10K happened.
Carrier frequency technique is a proven technique to suppress many of these errors but not all.
Fig. 3 shows the block diagram of a carrier frequency amplifier. The transducer is fed by an alternating voltage and works therefore like a modulator.

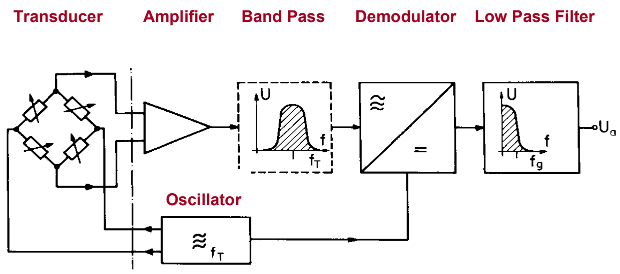


Fig. 3 Principle of Carrier Frequency Amplifier

If e.g. a mechanical 60 Hz vibration signal is to be measured and the power line induces a 60 Hz error signal at the same time, both signals can easily be separated using carrier frequency technique. The 60 Hz interference is damped by the band pass, then frequency-transformed in the range of the carrier frequency by the demodulator and at last suppressed by the low pass filter, whereas the carrier frequency-modulated mechanical 60 Hz signal passes the band pass, is frequency-transformed to 60 Hz by the demodulator and can then also pass the low pass filter undamped at the output.

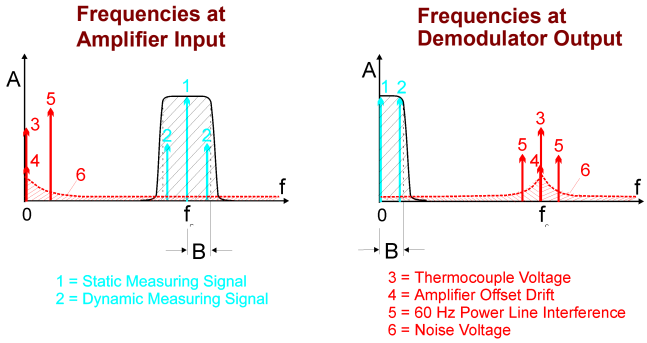
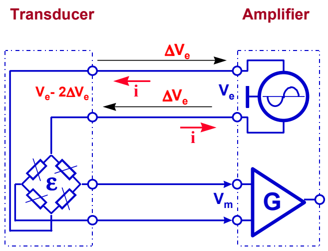


Fig. 4 Frequency Transformation by Carrier Frequency Technique

Fig. 4 shows the signals at the amplifier input and at the demodulator output. A static measuring signal is represented by the amplitude (1) with the carrier frequency. Dynamic measuring signals (2) are limited by bandwidth B and are also represented by frequencies in the range of the carrier frequency. Many error signals have frequencies close to zero. These are thermocouple voltages (3), amplifier offset drift (4) and also the 60 Hz power line interference (5). After demodulation the signals change place. A frequency transformation takes place and now the static measuring signal (1) possesses its true zero-Hz frequency, whereas the original zero-Hz thermocouple voltages (3) are transformed to carrier frequency f_C.
There is also a frequency transformation of the noise voltages (6). The more disturbing 1/f-low-frequency noise can also be suppressed by the carrier frequency technique whereas the smaller level of white noise is firmly related to the measuring signal range.

5 6-WIRE CIRCUIT WITH AUTO- CALIBRATION CYCLE

Carrier frequency is the means to get high resolution and to suppress many error sources. But there are some other problems left. The transducer and the measuring instrument are not the only parts of a measuring chain. There is always a cable between them. And this cable can cause large measuring errors.
If an extension cable is connected between transducer and measuring instrument the supply current (i) causes a remarkable voltage drop in the two bridge excitation wires which reduces the sensitivity of the measuring chain.
Fig. 5 shows the sensitivity reduction as a function of the cable length. A simple countermeasure is to make a new



Cable Length in m	Voltage Drop at Room Temperature	Change of Voltage Drop per 10 K
0,01	4	0
0,10	41	2
1,00	408	16
10,00	4065	159
100,00	39216	1529

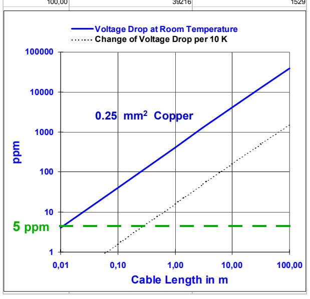


Fig. 5 Excitation Voltage Drop with 4-Wire Circuit (350Ω transducer and 0.25 mm^2 copper-wires)

calibration which includes the extension cable. But this solves only a part of the problem. The resistance change of the copper wires as a function of the ambient temperature change is still working. Fig. 5 shows that a 350Ω transducer connected by a 4-wire extention cable with 0.25 mm^2 copper-wire cross-sections reduces the sensitivity by 1% (10.000 ppm) when the cable length is 25 m and that a cable length of only 0.5 inch generates a gain reduction as high as the accuracy class (5ppm) of a high-precision measuring instrument. The gain drift per 10K of only one foot of cable length exceeds also the accuracy class of 5 ppm. That is why 6-wire circuits, as shown in Fig. 6, must be used.
(These arguments about calibration and temperature errors are not valid for the 4-wire transducer cable which is an integral part of an transducer. But also this statement is only valid as long as the transducer and its cable keep the same temperature).

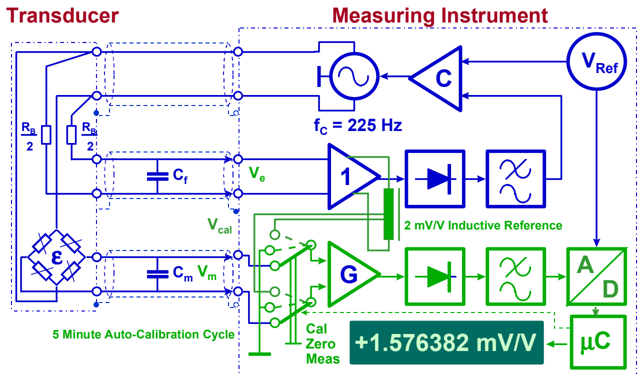


Fig. 6 6-Wire / Two-Channel Circuit with Auto-Calibration Technique

The excitation voltage V_e is tapped at the transducer supply input and fed back to the amplitude control of the measuring instrument. The excitation voltage generator then increases its output voltage by the voltage drop of 2*□ V_e and the transducer therefore gets always the right excitation voltage of V_e at its input.
Fig. 6 also shows another important principle. The reference voltage V_{ref} is fed to the amplitude control as well as to the reference input of the A-to-D-converter. By doing this every change of the reference voltage is of no impact on the measured value because the measuring voltage at the input of the ADC and the reference voltage of the ADC then change proportionally.
But there are some unsolved problems left. When carrier frequency is used, capacitive and inductive coupling occurs between adjacent wires. The most dangerous coupling C_{em} is between excitation and measuring wires because the excitation voltage is 500 times higher than the nominal measuring voltage. But also the capacitive coupling C_m between the two wires of the measuring voltage V_m causes a phase shift and an amplitude decrease because the 350Ω output impedance of the transducer and the capacity C_m build a low pass filter.

The cross coupling between excitation voltage and measuring voltage wires can simply be suppressed by separately shielding and twisting the three-wire pairs. The shielding helps against capacitive coupling whereas the twisting suppresses most of the inductive coupling. Shielding is of course also necessary to avoid EMI influences. However, this special shielded transducer cable cannot eliminate the coupling capacity C_m between the two measuring wires even if each single wire would possess its own shielding. But this error source can be compensated by treating the feedback voltage V_f the same way as the measuring voltage. For this the two resistors Rb/2 are included after tapping the feedback voltage. The measuring source impedance and the feedback source impedance then are equal and therefore phase shift and sensitivity changes of measuring and feedback voltages will also be equal. The control loop of the excitation voltage stabilises the feedback voltage V_f at the exact excitation voltage level V_e with the effect that also the measuring voltage rises to the exact level V_m at the amplifier input. With this method the measuring voltage V_m and the feedback voltage V_f at the inputs of the amplifier can be made unaffected by extension cables and held at their precise levels. That is why the error impact of the extension cable can be suppressed completely.
What are the error sources still left? These are the gain drift and in spite of carrier frequency technique also some zero point drift of amplifier, excitation voltage generator and ADC. The counter-measure for these errors is the auto-calibration technique also shown in Fig. 6.
If e.g. every 5 minutes the amplifier input is automatically switched to zero signal and after this to a very precise 2 mV/V reference signal and measurements are taken and stored, a micro computer then can easily adjust zero point offset and range deviation of the instrument very precisely. But it needs a very precise and stable mV/V-reference signal. A mV/V-reference is a voltage divider which should be connected to the feedback voltage V_e.
Dividers with the highest precision and best long-term stability are inductive dividers which can only be used if the transducer is supplied with carrier frequency. This is a second very strong argument for the use of carrier frequency technique. A rather low sinusoidal carrier frequency of 225 Hz fits very well to build high-precision instruments. With a low 225 Hz carrier frequency the amplifier gain is very stable and the frequency is already high enough to build small and very stable inductive dividers.

6 REALISATION OF PRECISION MEASURING INSTRUMENTS

According to the theory described above we developed a precision instrument called DMP39 already in 1980 which offers 1.000.000 digital steps resolution for 2 mV/V-signals and an accuracy class of 5 ppm. One of the first problems was: How can such an instruments be calibrated? And due to the fact that no suited calibration systems were available on the market we developed our own Inductive Calibration Unit.

There was already a lot of literature at this time how to build very precise passive inductive dividers. But because the results of these designs were always bulky big circuits, we took some electronics into the design and got a small, simple, precise and stable inductive divider.
Fig. 7 shows the principle of this inductive divider circuit. The error influence of the voltage drop across the copper resistance in the primary windings is cancelled by feeding back the induced voltage from a current-free secondary winding.

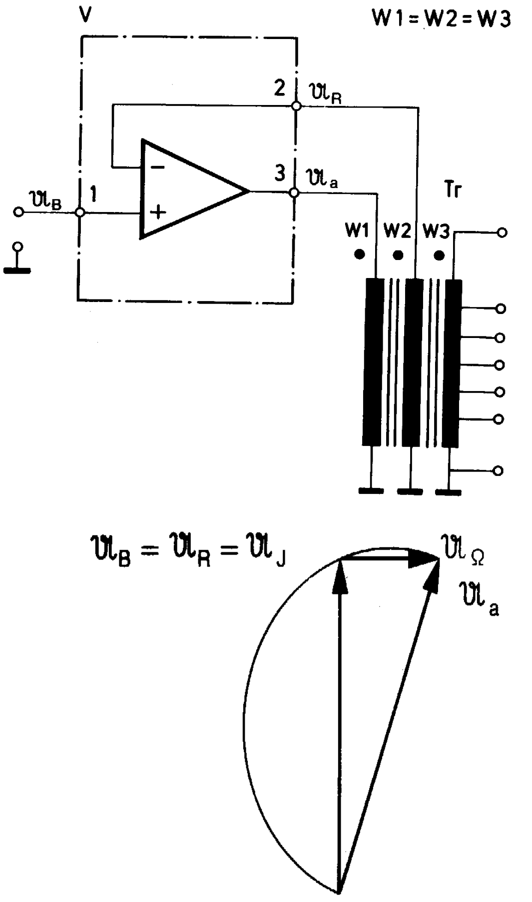


Fig. 7 Inductive Divider with Electronic Error Correction

On the basis of this circuit principle we built our own BN100 calibration unit and also very stable 2 mV/V reference voltage dividers for our amplifiers. Since 1981 we continuously observed the long-term stability of the measuring chain “DMP39 and BN100“ and can state that over now 18 years its span variation for + 2 mV/V- and -2 mV/V-signals was every time smaller than the accuracy class of 5 ppm.
When all error signals are sufficiently suppressed by the methods described above, the measuring signal itself has sometimes unwanted dynamic signal components caused by vibration or pendulum of masses. If heavy masses are involved the frequency of the dynamic signals can be very low. Examples for this are liquid flow measurements when a big tank is filled up and the change of weight per time is measured. Then the liquid may swash to and fro.
Other very extreme examples are the force comparison measurements with dead weight machines. The pendulum frequencies here often are as low as 0.2 Hz (one swing period in 5 s).

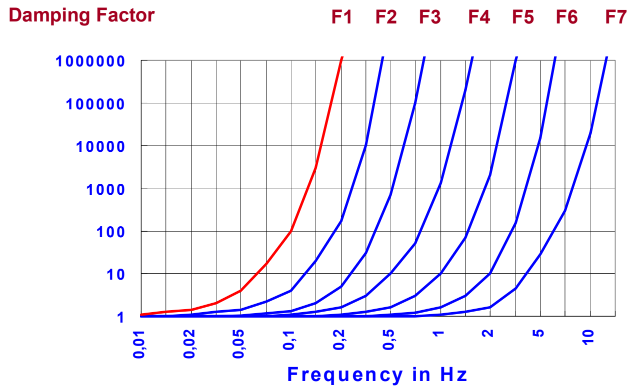


Fig. 8 Digital Filter with very high damping

Today it is quite easy to build very efficient digital filters with the aid of digital algorithms and put them into micro-computer software. We developed such special filters of 16^{th}-order and with damping factors > 1 Mio down to frequencies of 0.2 Hz and integrated them into our high-precision measuring systems. With digital filters these very low filter frequencies can easily be achieved without the disadvantages of the analogue filters with their bulky and expensive components and increased drift errors.

DMP40

Fig. 9 A Modern Measuring Instrument with 5 ppm accuracy class

Digital filters are crystal controlled. Therefore their filter characteristics, delay times and damping factors are reproducible, stable, precise and equal in different measuring channels. This is a very important feature if two transducer signal are measured simultaneously. The measurements can then be correlated without failure.
The new type DMP40 high-precision instrument has all the above mentioned features. Its resolution is 2.000.000 digital steps and its accuracy class is 5 ppm. There are two versions of this instrument. The DMP40 has got one amplifier whereas the DMP40S2 has got two simultaneously measuring amplifiers. Each amplifier can supply 8 transducers continuously and measure them one by one. So with the DMP40S2 measurements can be taken when signals of two transducers change continuously and must be measured at the same time as in situations when master-specimen load tests are done in hydraulic force machines. Any transducer (1 out of 8) of amplifier 1 can be measured simultaneously with any transducer (1 out of 8) of amplifier 2.

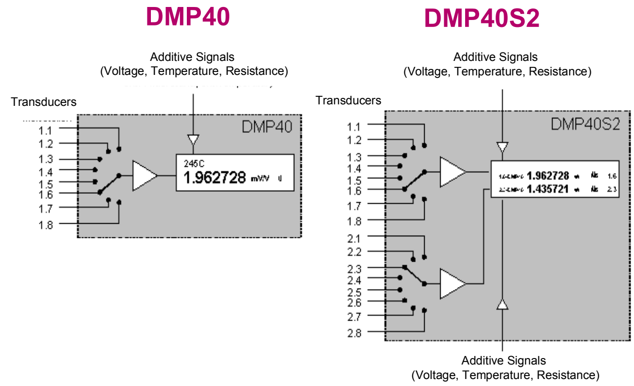


Fig. 10 Precision Measuring Instruments with 8 or 16 channels

The display can show the measurement of two channels at the same time. Additionally the maximum and minimum measurements, lots of status information, excitation voltage and user comments can also be displayed. Each of the 16 transducers can be linearized individually.
Auxiliary channels to measure ambient temperature, transistor resistance and load currents are standard. With a simple key stroke the display switches from physical quantity to mV/V values. The tared signal (net), the zero balanced signal (gross) and the unchanged absolute input signal (abs) - which is often helpful to judge the condition and reliability of the connected transducers - is also selectable. There are other features like limit value detection, user programmable soft-keys, printing functions, password security, etc. RS-232-C, IEEE-488 and Ethernet (optional) interfaces provide full remote control by computers

7 NEW STRUCTURE FOR UNIVERSAL AND PRECISE AMPLIFIER SYSTEMS

The question is: can all the above described methods be applied on standard amplifier system?
To answer this let's first have a look on the structure of usual standard measuring systems.

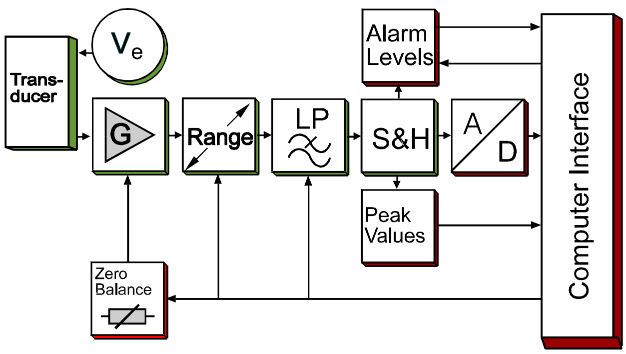


Fig.11 Standard structure of amplifier systems

Most of the functionality is realised by special electronic circuitry. These are, for example, circuits for switching the measuring range, for the zero point adjustment and for signal filtering. These circuits are really complex and give rise to errors due to component tolerances and parameter change. In particular, the complexity required for the zero balancing networks is very high. Especially when measurements are taking place in the sensitive ranges, an extraordinarily high level of resolution and stability is required for zero balance, as already explained in Fig. 1.

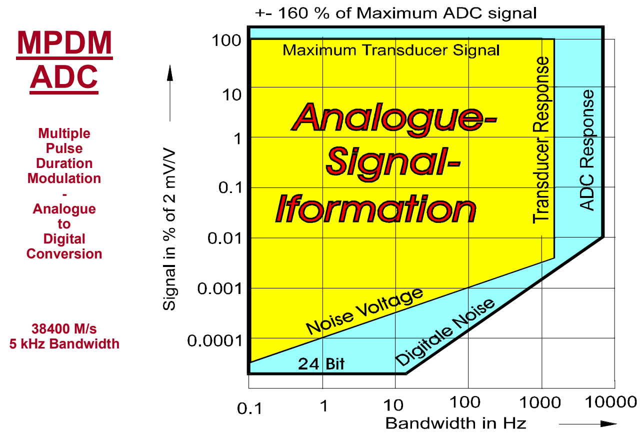


Fig.12 Digital data keeps 100% of analog information

The high gain needed on the sensitive measuring ranges has the undesired characteristic in that the dynamic parts of the measuring signals as well as interference signals in the input circuit, e.g. due to power line or electromagnetic interference, can easily overdrive the amplifier input stages. Therefore a circuit solution which would not need range switching and a zero balancing circuits could work much better. The requirement for this is an fast and precise ADC which can digitise the whole signal range from nominal load down to noise signal levels in one range with full bandwidth and sufficient resolution.
Fig. 12 shows the signal range of normal strain gage transducers. The signal amplitude is limited in upwards direction by the maximum permissible rated load on the transducer. In the direction towards low amplitudes the signal is physically limited by the thermal noise voltage. At high frequencies the transducer signal is limited by the dynamic response of the transducer, due to its mechanical resonance relationship of mass and stiffness.
The digitisation technique developed and patented by HBM provides a high conversion rate of 38400 M/s, a signal bandwidth of 5 kHz and a resolution up to 24 bit.
Fig. 12 shows that the range of digital data is in every aspect larger than the analogue signal range of strain gage transducers. Therefore the analogue transducer signals are converted into streams of digital data without loosing information, neither in amplitude or resolution nor in speed. Because the digital signal information is identical to the analogue signal information all data conditioning and processing functions can now be done digitally by means of computer algorithms and the amplifier structure gets very simple as shown in Fig. 13.

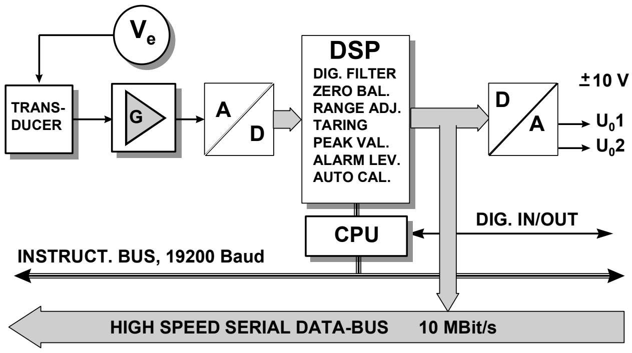


Fig.13 Block Diagram of an amplifier with digital data conditioning and processing

The analogue circuit part can be reduced to the bridge excitation voltage and a simple input amplifier. This amplifier needs only low gain and matches the transducer to the ADC.
After digitisation the signal filtering, zero balancing, taring and also rang adjustment is done digitally by ASICs or micro computer circuits. Because these functions are carried out with crystal controlled algorithms they are almost errorless. They are not influenced by component tolerances, temperature change or long-term drift. Power consumption and necessary space can be decreased drastically and precision can rise significantly. E.g., a simple subtraction calculation can now replace the former very expensive but nevertheless error prone zero balancing circuits. With a DAC the conditioned digital data is converted back to a +-10 V analogue signal.
Additionally to the analogue output, these amplifiers provide a digital output which transmits the digital measuring data on a serial data line with 10 MBaud speed to the central processing unit of the system. So each of such amplifiers is a complete system, providing the measurement signals not only in the common analogue but also in a digital representation.
Because all signal conditioning and data processing is done by computer algorithms, it is very easy to remote control such amplifiers in all their functions by transmitting appropriate instructions across a serial interface like RS 232-C.

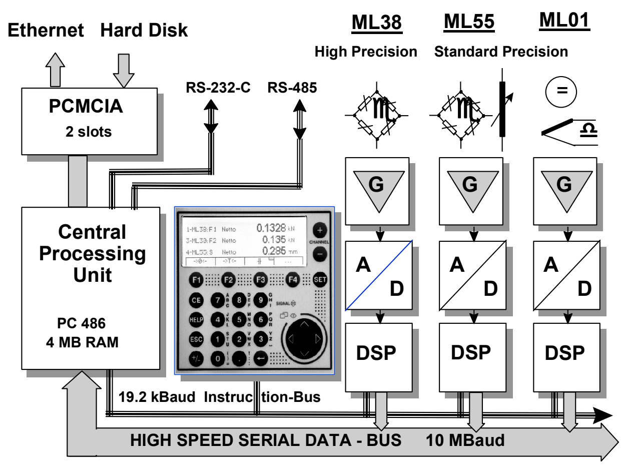


Fig.14 Block Diagram of a “Digital“ Amplifier System

In Fig. 14 the block diagram of the whole MGCplus Amplifier System is shown. All common transducers like strain gage, inductive, resistive or piezo-electric transducers, thermo-couples as well as voltage and current sources can be measured by the system with different specialised amplifiers. Tab. 1 gives an overview of the available amplifiers and their main purposes. All amplifiers work with auto-calibration and very stable reference signal sources.

Type	Accur. Class	$f_{carrier}$ / f_{-3dB}	Input signals / transducers
ML38	0.0025%	225 Hz / 10 Hz	Strain gage full bridge
ML01B	0.03%	DC / 3 kHz	Thermocouples, voltage, current
ML10B	0.03%	DC / 75 kHz	Resistive half- or full-bridge / piezo-electric transducers
ML30B	0.03%	600 Hz / 277 Hz	Strain gage quarter-, half- and full-bridge (AP14)
ML35B	0.03%	75 Hz / 23 Hz	PT10, PT100, PT1000 / resistors 0....5000Ω
ML50B	0.03%	4.8 kHz / 2.2 kHz	Inductive half- or full-bridge
ML55B	0.03%	4.8 kHz / 2.2 kHz	Strain gage half-/full-bridge / inductive half-/full-bridge
ML55B-S6	0.03%	9.6 kHz / 3.6 kHz	Strain gage half-/full-bridge / inductive half-/full-bridge
ML60B	0.01%	- / 2 kHz	Torque transducers / frequency input 0.1 Hz ...2 MHz

Tab. 1 Selection of MGCplus amplifiers

For high precision measurements with strain gage transducers the ML38 is the first choice.
It provides a resolution of up to 1.000.000 d and an accuracy class of 25 ppm. Its carrier frequency is only 225 Hz to minimise capacitive errors and therefore its maximal bandwidth is only 10 Hz. But there are 600 Hz carrier frequency amplifiers (also for ¼-bridges) with 200 Hz bandwidth and 4.8 and 9.6 kHz carrier frequency amplifiers with up to 3 kHz bandwidth. A broadband DC amplifier provides 50 kHz (-1dB) bandwidth for the analogue output signal and 3 kHz bandwidth for the digital measurement. All amplifiers are synchronised and transmit their simultaneously measured data via a the 10 MBaud serial data-bus to a Central Processing Unit which collects and buffers the data. A hard disks can be plugged into PCMCIA slots and several hundred millions of measurements can be stored, sufficient for almost every kinds of tests. The second PCMCIA slot can hold an Ethernet interface which enables very fast data transfer. Inside the system all amplifier setting data is transmitted over a 19.2 kBaud instruction-bus, either from the central processing unit or a special display and control unit (AB22A). A 19“ housing of a MGCplus system can contain up to 16 standard amplifier or 8 high precision ML38 amplifier because the high precision amplifier ML38 need the space of two standard amplifier slots.
A powerful PC software package called catman® supports the MGCplus, the DMP40 and all other HBM measuring systems and provides a broad scope of instrument set-up programs, virtual front panels, data acquisition, online graphics, data processing and data analysing functions.
The operation of all system settings can be done via virtual front panels by simple mouse clicks on your PC in an intuitive and easy way.

Fig. 15 16-Channel Amplifier System

8 CONCLUSION

In the field of high precision measuring technique it is necessary to calibrate transducers and measuring instruments separately. For this purpose the measuring instruments must measure the transducer output signals in mV/V as precise as possible without loading or otherwise corrupting the transducer signals and by avoiding any dependence between measurement and transducer resistance (input as well as output resistance). All error signals must be suppressed as good as possible and the zero point and span stability must be made extremely high.
The means to achieve these goals are low frequency carrier-frequency-technique, inductive reference dividers, auto-calibration cycles and a sophisticated 6-wire/2-channel technique. With these methods applied instruments with 2.000.000 digital steps resolution per 2 mV/V and an accuracy class of 5 ppm were realised. By aid of a fast but nevertheless very precise ADC-technique the philosophy of the high precision technique was extended to amplifier systems. They now can also work with a simple one-range analogue amplifier, avoiding the expensive and sometimes faulty zero balancing and range switching circuits because all signal conditioning functions like zero balancing and range adaptation is done errorless by computer algorithms with aid of gate-arrays circuits. Therefore it is possible now to integrate amplifier with highest precision together with broad-band standard amplifiers into one measuring system to measure e.g. forces or masses with very precise and to get additional information about temperature, pressure and other auxiliary physical unit with standard accuracy.