

"Process for automatically calibrating wideband microwave modules"

The present invention relates to a process for automatically calibrating microwave modules able to operate in a wide range of radio signal frequencies and strengths.

It is known in the technical sector of microwave systems which operate in a wide range of frequencies, as for example in the case of wideband microwave receivers or wideband microwave frequency generators, that the microwave modules which process these signals must ensure that the amplitude of the signal remains constant within the entire operating band, while the basic components, amplifiers, filters and attenuators, which are used in said microwave modules, tend to have a non-uniform behaviour within the band and normally tend to distort the signal, attenuating it with an increase in the frequency.

It is also known that said modules, and in particular those modules associated with wideband receivers, must operate in a wide frequency band and with signals which, since they may have widely differing strengths, require filtering structures with optimum selectivity, dynamic-range and equalization characteristics in order to obtain intermediate band signals with a constant amplitude and phase upon variation in the frequency and strength characteristics of the signal received, while ensuring at the same time the necessary sensitivity and linearity required for correct operation thereof.

An example of this need exists in the receivers used in systems designed so as to determine the basic characteristics of electromagnetic signals received within a wide frequency band which ranges from short waves to millimetric waves, such as RADAR systems.

Since in receivers the gain of the input/output transfer function varies greatly upon variation in the frequency, in particular gradually decreases with an increase in the latter, in wideband receivers there is a corresponding distortion of the signals which increases with an

increase in the operating band and which may render the signal received unintelligible.

Consequently, the need for alignment, according to the design specification, of the signal output by the microwave module requires that compensation of the module transfer function be introduced so that the signal supplied at the output is not distorted and is contained within a pre-defined dynamic range upon variation in the frequency and the power of the signal received.

It is also known that the alignment operation, i.e. the operation which ensures that the output signal complies with the requisites of the design specification upon variation in the input signal, is obtained by using special circuits (alignment circuits) consisting of basic components which can be calibrated (filters, attenuators, amplifiers and equalizers) able to align the signal received to the specification requirements; these circuits must be able to be calibrated since, during design both of the individual components which form them and of the circuit as a whole, tolerances are defined which are not sufficiently small to ensure compliance with the necessary operating specification.

Consequently, in order to obtain the desired transfer functions, it is required to carry out complex calibration on the test bench of all the components, able to compensate for the effects due to said intrinsic tolerances of the components. Calibration, which is already complicated under normal conditions, is also particularly complex in those cases - for example wideband applications - where strict specifications require a high operating precision of the circuit.

In addition, the calibration and test activity becomes even more critical when the apparatus is required to function, according to specification, within a wide temperature range, as occurs for example in the aforementioned applications and in particular when this is required for receiver systems which operate in a temperature range of -40 to 70°C, since there is a further variability in the parameters which is

dependent not only on the temperature, but also on the basic components and therefore the transfer function of the circuit itself.

It is also known that the various components of the alignment circuit may be calibrated manually; however, especially with regard to equalizers, calibration is particularly complex since each component must be calibrated individually and/or replaced manually, until the combination which complies with the system requirements is found.

Therefore, the production and calibration of alignments circuits for microwave receivers is extremely complex, difficult and critical since it depends to a great extent on the ability of the specific operator responsible for calibration and testing.

A similar problem exists also for other types of circuits which operate with a wide band in the microwave frequency range, as for example in the case of the following frequency generators: e.g.:

- in so-called "comb generators", which are used to obtain immediate and simultaneous availability of several signal sources distributed within a very wide spectrum, there is a significant lack of uniformity in the amplitude of the output components and an associated instability of the amplitude depending on the temperature;
- similarly, wideband frequency generators of the synthesized type, whether they be phase/frequency locked-loop (PLL/FLL) synthesizers or direct digital synthesizers (DDS), since they have a variable-frequency voltage controlled oscillator (VCO) and are used in the field of communications with a very wide radiofrequency band, require correction of the amplitude of the output characteristic so as to compensate for the variations due to the different set frequency and changes in temperature.

The technical problem which is posed, therefore, is provide a process for allowing rapid automatic calibration of wideband microwave modules, which is to a large extent independent of the abilities of the individual operator responsible for performing the operation.

In connection with this technical problem it is also required that the process should be simple to implement and allow a reduction in the complexity and corresponding production costs of the said devices to be calibrated.

These results are achieved according to the present invention by the provision of a process for automatically calibrating, according to pre-defined specification values of a plurality of calibration parameters ( $G_{m-min-spec}$ ;  $G_{m-max-spec}$ ;  $T_i$ ;  $V_i$ ;  $B_i$ ), a wideband microwave module comprising at least one basic alignment circuit each comprising at least one filter, followed by at least one variable amplifier, by a variable attenuator and by a variable equalizer, the voltage input/s of which can be controlled, being supplied with frequency signals lying within different bands ( $B_i$ ) and operating at different temperatures ( $T_i$ ), and for which at least the following calibration parameters have been defined according to specification values:

- temperatures  $T_1, T_2, \dots, T_i$  at which test cycles of the automatic calibration cycle must be performed;
- nominal start-of-procedure input voltages ( $V_{1i}, V_{2i}, V_{3i}, V_{4i}, V_{5i}, V_{6i}, V_{7i}$ );
- $G_{m-max-spec}$  = Maximum gain of the alignment circuit/s, according to specification, for each band;
- $G_{m-min-spec}$  = Minimum gain of the alignment circuit/s, according to specification, for each band;

there being provided an intermediate frequency conversion block, which performs conversion to the intermediate frequency of the signal incoming from the alignment circuit/s and which has an output;

characterized in that it comprises the following steps:

- 20) initial configuration of a PLC controller with storage of the said start-of-procedure input voltages ( $V_{1i}, V_{2i}, V_{3i}, V_{4i}, V_{5i}, V_{6i}, V_{7i}$ ) in a static memory of the PLC controller itself;
- 30) automatic application of the said start-of-procedure input voltages ( $V_{1i}, V_{2i}, V_{3i}, V_{4i}, V_{5i}, V_{6i}, V_{7i}$ ) to the respective input points of the respective amplifier/s, attenuator/s, and equalizer/s of the basic alignment circuit/s ;
- 31) introduction, into the PLC memory, of pre-defined values of calibration parameters of the calibration cycle which are specific for

each microwave module to be calibrated and comprise at least:

- the number  $N_B$  of bands ( $B_i$ ) of the microwave module to be calibrated; there being provided three frequency sub-bands, plus one direct band;
- the temperature values  $T_i$  at which the test cycles of the calibration cycle are to be performed;

40) CALIBRATION CYCLE upon variation of the temperature:

41) for each pre-defined temperature  $T_i = T_1, T_2, T_3$

42) setting the temperature of the microwave module to the test temperature  $T = T_i$ ;

50) Calibration of the variable equalizers of the at least one basic alignment circuit for each band for which the microwave module must operate;

51) application of a test signal to the input of an input block connected to an antenna for each frequency band ( $B_i$ ) of the signals input into the module;

51a) measurement of the slope of the gain of the alignment circuit or of the slope of the amplitude of the signal in the band  $B_i$  at the output of the intermediate frequency conversion block,

52) COMPARISON between the slope measured and a characteristic slope of a design specification:

52a) slope measured > slope of the design specification?

YES-> reduction of the slope of the operating band ( $B_i$ ) by suitably modifying the voltages ( $V_6$ ) and ( $V_7$ ) applied to respective adjustment points of the equalizer for the band ( $B_i$ ); and repetition of the comparison cycle (51a, 52, 52a; 52b);

NO->

52b) slope measured < slope of the design specification?

YES-> increase of the slope of the operating band ( $B_i$ ) by suitably modifying the voltages ( $V_6$ ) and ( $V_7$ ) at the respective adjustment points of the equalizer for the band ( $B_i$ ); and repetition of the comparison cycle (51a, 52, 52a; 52b);

NO->

53) repetition of the cycle (51-52) for each band ( $B_i$ ) of the input signals;

70) Calibration of the amplifier/s and the attenuator/s of the basic alignment circuit/s;

71) for each frequency of the bands ( $B_i$ );

72) measurement of the average gain ( $G_{m1}, G_{m2}, \dots, G_{mNB}$ ) of the transfer function of the microwave module between the input of the input block and the output of the frequency conversion block;

73) calculation of the value  $G_{m-max} = \max(G_{m1}, G_{m2}, \dots, G_{mNB})$ ;

74) calculation of the value  $G_{m-min} = \min(G_{m1}, G_{m2}, \dots, G_{mNB})$ ;

75) comparison between  $G_{m-max}$  and the specification value  $G_{m-max-spec}$ ;

75a)  $G_{m-max} > G_{m-max-spec}$ ?

YES-> the amplification is decreased and the attenuation is increased in the basic alignment circuit for the band  $B_i$  corresponding to  $G_{m-max}$  by adjusting the input voltage ( $V_1$ ) of the associated amplifier/s and the input voltage/s ( $V_4, V_5$ ) of the associated attenuator/s;  
repetition of the cycle (72,73,74,75+75a);

NO->

76) Comparison between  $G_{m-min}$  and the specification value  $G_{m-min-spec}$

76a)  $G_{m-min} < G_{m-min-spec}$ ?

YES-> the amplification is incremented and the attenuation is decreased in the basic alignment circuit for the band ( $B_i$ ) corresponding to  $G_{m-min}$  by adjusting the input voltage ( $V_1$ ) of the associated amplifier/s and the input voltage/s ( $V_4, V_5$ ) of the associated attenuator/s;  
repetition of the cycle (72,73,74,75,76,76a);

NO->

80) Storage of the values of the said adjusted input voltages ( $V_1, V_4, V_5$ ) corresponding to respective values of the temperature ( $T_i$ )

in the memory of the PLC;

- 90) Repetition of the entire cycle for each temperature ( $T_i$ ).
- 140) Start of an automatic test procedure;
- 150) Generation of a test sheet of the microwave module.

Further details may be obtained from the following description of a non-limiting example of embodiment of the subject of the present invention provided with reference to the accompanying drawings in which:

Figure 1: shows the circuit diagram of an example of a microwave module to be calibrated;

Figure 2: shows the circuit diagram of an example of embodiment of a variable amplifier for an alignment circuit according to the present invention;

Figure 3: shows the circuit diagram of an example of embodiment of a variable attenuator for an alignment circuit according to the present invention;

Figure 4: shows the circuit diagram of an example of embodiment of a variable equalizer for an alignment circuit according to the present invention;

Figure 5: shows the flow diagram illustrating the process for calibrating a microwave module according to the present invention;

Figures 6, 7 and 8: show the block diagram of a comb generator during calibration and the respective graphs for its output before and after calibration; and

Figures 9, 10 and 11: show the block diagram of a synthesized generator during calibration and the respective graphs for its output before and after calibration.

As shown in Figure 1 an example of a microwave module for receiving wideband frequency signals (ranging from radio frequencies to millimetric waves), which may be calibrated and tested by means of the process according to the present invention, comprises:

- an input block 1000, connected to the wideband antenna, from which it receives:
  - a plurality of input signals 1001, 1002, 1003, 1004, which are sent to a respective directional coupler 1005 which allows the signal received to be sent also to an output 1007 towards a second receiver;
  - an input signal 1006 to which the signals for the calibration and control operations described below are applied;
- a switch 1010 which, receiving any one of the input signals, sends them to a filter 1015 in order to limit their operative frequency band and therefore reduce their harmonics or the spurious emissions produced by unwanted signals;
- a dynamics block 2000 which receives at its input the signal output by the filter 1015 and has the function of adjusting the dynamic range thereof.

This module contains a high-sensitivity circuit 2010 which comprises a signal limiter 2011 inserted so as to protect a following low noise figure amplifier 2012 in the presence of signals with high strength levels, these components being followed by an attenuator 2013 and by an amplifier 2014 which have the function of ensuring the gain, the dynamic range and the design sensitivity along the high-sensitivity path.

The signal 2010a output by the high-sensitivity circuit 2010 is intercepted by a recognition circuit 2020 by means of which it is possible to detect the strength of each signal and drive a corresponding switch 2030 which diverts each signal to a corresponding attenuator 2031, 2032, 2033 of different value.

By means of the said functional circuits it is possible to determine, for each signal of varying strength, the corresponding path with a suitable dynamic range so as to reduce the harmonics, the intermodulation products and the spurious emissions produced by signals present outside the operative sub-bands of the channel selected for conversion;

- a block 3000 containing the circuitry for aligning the signal according to the requisites of the design specification, which comprises:
  - an input power limiter 3010 for protecting the following circuits,
  - a multi-path switch 3020 (four-path in the example shown in the figures),
  - at least one basic alignment circuit 3100 for at least one signal within a given frequency band; the number of basic alignment circuits depends on the number of output bands from the preselector module; the example according to Figure 1 shows three basic alignment circuits.

Each basic alignment circuit 3100 comprises at least one filter 3110, followed by at least one variable amplifier 3120, by a variable attenuator 3130 and by a variable equalizer 3140 which are arranged in series and the voltage of which can be controlled, so as to be able to perform calibration of each channel.

As shown in Figure 1 it is envisaged that, depending on the frequency of the signal received, some of the basic alignment circuits 3100 are followed by a further block 3200 comprising a variable amplifier 3120 and a variable attenuator 3130 necessary for alignment with the specified requisites.

The basic alignment circuits also comprise a further output filter 3300 and are connected to a switch 3400 which selects the circuit and therefore the corresponding signal 3400a to be sent to a following frequency conversion block 4000.

The block 4000 which performs conversion to the intermediate frequency of the incoming signal 3400a at the microwave/RF band frequency.

Said block 4000 comprises at its input a variable-gain amplifier 4201 and a variable attenuator 4202 followed by a frequency converter 4100 which receives at its input also a signal 4101 from a local oscillator which generates the tuning frequencies for converting the high-frequency channels into intermediate-frequency channels for subsequent processing.

The block 4000 also comprises a filter 4250, an amplifier 4300 and variable attenuator 4400 arranged in series so that it is possible to compensate for the maximum output power and the mean value of the gain in the entire operating band, before the signal is sent to the output 4002 for subsequent processing.

Figures 2, 3 and 4 show examples of functional/electrical diagrams of said basic components, amplifier, attenuator and equalizer which can be calibrated and form the basic alignment circuits.

In greater detail Figure 2 shows the functional diagram of an amplifier 3120, the gain of which can be varied by modifying the gate voltage V1 applied to the input 3121 of the device.

The amplifier is designed by means of the known "travelling" solution via which it is possible to obtain wideband amplification.

The input signal, for example supplied by the switch 3020, is introduced into the connector 3124 and the amplified output is extracted by the output connector 3125.

The six GaAs FETs 3126 in a dual gate configuration, which amplify the signal, are polarized by means of the drain voltage V2 applied to

the input 3122 and the gate voltages V1 and V3 applied to the respective input 3121 and 3123.

As can be noted from Figure 2, the induction lines of gates connected to the capacitances Cgs 3128a of the FETs and the drain induction lines connected to the capacitances Cds of the FETs form two low-pass filters.

By suitably designing the dimensions of the two gate and drain lines so as to compensate for the capacitances Cgs 3128a and Cgd it is possible to obtain amplifiers, the cut-off frequency of which exceeds 30 GHz.

Figure 3 shows the functional diagram of a variable attenuator 3130, the function of which is to vary the average frequency attenuation.

The operating principle is that of a conventional pi attenuator. By suitably varying the polarization voltage V4 at the input 3134, for the PIN diodes CR1 and CR2, and the voltage V5 at the input 3135, for the diode PIN CR3, it is possible to vary the three junction resistances thereof and therefore the attenuation of the device.

The direct voltage values on the three diodes must be suitably set taking account also of adaptation of the device on the line with a characteristic impedance of 50 ohm.

Figure 4 shows the functional diagram of an equalizer 3140 which has a slope variable discretely - forming the subject of the co-pending patent application IT-RM2009A000022 referred to here in its entirety - and which has between the input gate 3141 and the output gate 3142 a transfer/attenuation function inversely proportional to the frequency and adjustable by means of the voltages V6 applied to the input 3146 and the voltage V7 applied to the input 3147, which determine the different conduction/inhibiting conditions of the diodes D3, D4, and D1, D2 able to compensate for the effect of loss of insertion of a

radiofrequency chain which is generally directly proportional to the frequency.

Since this device introduces a characteristic which is the inverse of that of the RF chain, by suitably adjusting the voltages V6 and V7, it is possible to obtain a function for transfer of the flat unit into frequency.

By suitably programming the variable equalizer, it is possible to compensate automatically for the variation in the slope produced by the tolerances of the components used in the RF chain of the modules in question.

According to the invention it is envisaged that the microwave module is equipped with a controller 5000 of the PLC type (programmable logic device) provided with its own static memory by means of which it is possible to control the said regulating voltages (V1,V2,V3,V4,V5,V6,V7).

### PROCESS

Figure 5 illustrates in the form of a flow diagram the process used for automatic alignment of the said microwave module which comprises the following steps:

#### PRELIMINARY PROTOTYPE CHARACTERIZATION STEP

- definition of the specification values which must be obtained by means of calibration of the microwave module, including
  - $G_{tot-m-spec}$  = Total average gain, according to specification, of the module;
  - $G_{m-max-spec}$  = Maximum gain of the alignment circuit, according to specification, for each band;
  - $G_{m-min-spec}$  = Minimum gain of the alignment circuit, according to specification, for each band;

- definition of the temperatures  $T_1, T_2, \dots, T_i$  at which the automatic calibration cycles must be performed.

Once the first prototypes of the circuit to be calibrated have been prepared, the nominal start-of-procedure input voltages ( $V_{1i}, V_{2i}, V_{3i}, V_{4i}, V_{5i}, V_{6i}, V_{7i}$ ) are determined on the basis of the design calculations and by means of tests on the calibration and alignment bench carried out on the prototypes;

### PROCESS STEPS

- 20) initial configuration of the PLC controller with storage of the said start-of-procedure voltages ( $V_{1i}, V_{2i}, V_{3i}, V_{4i}, V_{5i}, V_{6i}, V_{7i}$ ) in a static memory of the PLC itself;

30) automatic application of the said start-of-procedure voltages ( $V_{1i}, V_{2i}, V_{3i}, V_{4i}, V_{5i}, V_{6i}, V_{7i}$ ) to the respective input points (3121, 3122, 3123, 3134, 3135, 3146, 3147) of the respective amplifiers 3120, attenuators 3130, and equalizers 3140 of the basic alignment circuits (3100);

31) introduction, into the PLC memory, of the values of the parameters of the calibration cycle which are specific for the ~~circuit~~ module to be calibrated and comprising at least:

- the number  $N_B$  of bands  $B_i$  of the module to be calibrated; in the example according to Figure 1,  $N_B = 4$ , there being provided three sub-bands, plus one direct band;
- the temperature values  $T_i$  at which the test cycles are performed; in the example illustrated three calibration temperatures  $T_1=25^\circ$ ,  $T_2=-40^\circ$ ,  $T_3=70^\circ\text{C}$  are used;

**40) CALIBRATION CYCLE upon variation of the temperature**

41) for each pre-defined temperature  $T_i = T_1, T_2, T_3$

42) the temperature of the microwave module is raised to the test temperature  $T=T_i$ ;

50) Calibration of the variable equalizers 3140 of the alignment circuits 3100 for each band for which the circuit must operate;

51) application of a test signal to the input 1006 of the block 1000 for each band  $B_i$  of the signals input into the module;

51a) measurement of the slope of the signal in the band  $B_i$  at the output 4002 of the block 4000.

52) COMPARISON between the slope measured on the output signal 4002 and the characteristic slope of the design specification;

52a) slope measured  $>$  slope of the design specification?

YES-> reduction of the slope of the operating band  $B_i$  by suitably modifying the voltages  $V_6$  and  $V_7$  at the respective adjustment points (1006, 1007) of the equalizer for the band  $B_i$ ; and repetition of the comparison

NO->

52b) slope measured  $<$  slope of the design specification?

YES-> increase of the slope of the operating band  $B_i$  by suitably modifying the voltages  $V_6$  and  $V_7$  at the respective adjustment points (1006, 1007, ) of the equalizer for the band  $B_i$ ; and repetition of the comparison

NO->

53) repetition of the cycle for each band  $B_i$  of the input signals;

60) CALIBRATION of the amplifiers 4300 and the attenuators 4400 of the common circuits IF 4000;

61) measurement of the average gain ( $G_{tot-m}$ ) in the entire operating band between the input 1006 and the output 4002 of the circuit module;

62) Comparison with the specification value ( $G_{tot-m-spec}$ ) defined during the design stage

62a)  $G_{tot-m} > G_{tot-m-spec}$ ?

YES-> the amplification 4300 is decreased and the attenuation 4400 of the common part IF is increased and the comparison repeated

NO->

62b)  $G_{tot-m} < G_{tot-m-spec}$ ?

YES-> the amplification 4300 is incremented and the attenuation 4400 of the common part IF is reduced and the comparison repeated

NO->

70) CALIBRATION of the amplifiers and the attenuators of the alignment circuits 3100;

71) for each band  $B_i$ ;

72) measurement of the average gain  $G_{m1}, G_{m2}, \dots, G_{mNB}$  of the transfer function of the circuit between the input 1006 and the output 4002;

73) calculation of the value  $G_{m-max} = \max(G_{m1}, G_{m2}, \dots, G_{mNB})$ ;

74) calculation of the value  $G_{m-min} = \min(G_{m1}, G_{m2}, \dots, G_{mNB})$ ;

75) comparison between  $G_{m-max}$  and the specification value  $G_{m-max-spec}$ ;

75a)  $G_{m-max} > G_{m-max-spec}$ ?

YES-> the amplification 3120 is decreased and the attenuation 3130 is increased in the basic alignment circuit for the band  $B_i$  corresponding to  $G_{m-max}$  by adjusting the voltage  $V1$  of the associated amplifiers and the voltages  $V4, V5$  of the associated attenuators;  
repetition of the cycle;

NO->

76) Comparison between  $G_{m-min}$  and the specification value  $G_{m-min-spec}$

76a)  $G_{m-min} < G_{m-min-spec}$ ?

YES-> the amplification 3120 is increased and the attenuation 3130 is decreased in the basic alignment circuit for the band  $B_i$  corresponding to  $G_{m-min}$  by adjusting the voltage  $V1$  of the associated amplifiers and the voltages  $V4, V5$  of the associated attenuators;  
repetition of the cycle;

NO->

- 80) Storage of the values of the alignment voltages (V1,V4,V5) corresponding to the temperature of  $T_i$  in the memory 5000 of the PLC;
- 90) Repetition of the entire cycle for each temperature  $T_i$ .
- 140) Start of the automatic test procedure;
- 150) Generation of the test sheet of the microwave module.

For certain specific applications where the sensitivity of the apparatus to be calibrated is important, as for example in the case of wideband receivers, the process according to the invention envisages further calibration steps comprising:

100) Measurement of the Noise Figure NF (NF = ratio between Signal/Noise input and Signal/noise output into/from the circuit) for each of the operating sub-bands  $B_i$ ;

110) Comparison between the measured value  $NF_m$  and the specification value  $NF_{spec}$

110a)  $NF_m$  not to spec?

YES-> the gain of the input preamplifier 2012 is increased;  
repetition of the entire calibration cycle for all the temperatures  $T_i$ ;

NO->

120) Measurement of the linearity of the transfer function between the input 1006 and the output 4200 for each of the sub-bands  $B_i$ ;

130) Comparison between the linearity measured and the specifications

130a) Linearity not to spec?

YES->increase in the attenuation of the input stage 2013;  
repetition of the entire calibration cycle for all the temperatures  $T_i$

NO->

140) Start of the automatic test procedure;

150) Generation of the test sheet of the microwave module.

Since, during automatic calibration, the values of the alignment voltages of the basic components of the circuit (amplifiers, attenuators, equalizers) are defined only for certain working temperatures (three: -40, 25, 70°C in the example), the values of the voltages for alignment

with the intermediate temperatures are calculated by means of interpolation of the values determined during calibration.

Consequently, in the operating mode, the programmable logic device installed in the module reads every second the temperature information by means of a digital temperature sensor and, based on the values of the alignment voltages defined during calibration for the three said calibration temperatures, calculates by means of interpolation the values of the optimum alignment voltages to be applied in the specific situation.

In a manner similar to that described above, the automatic calibration process may be applied to the alignment circuits of wideband microwave frequency generators.

Figure 6 shows a wideband frequency generator with frequency components distributed within the spectrum of the working frequencies. This generator, owing to the distribution of its components over a certain number of frequencies, is commonly referred to as a "comb generator".

A possible defect of this type of generator is the relative lack of uniformity in the amplitude of the output components 1a of the circuit 1 (Figure 7) and the relative instability of the amplitude depending on the temperature.

With the process according to the present invention it is possible to calibrate the alignment circuits using the automatic procedure described and ensure that the amplitudes present at the output 3400a of the alignment circuit 3000 are uniform within the band and stable in relation to the temperature (Figure 8).

The automatic calibration system will maintain a constant value for preselection of the variable amplifier and for preselection of the attenuator and will adjust exclusively equalization; it will therefore

supply the control parameters to the alignment circuits and these will be stored in the module memory.

Another example of application of the process according to the invention is shown in Figure 9 which shows the block diagram of a synthesized variable frequency generator 2, of the phase/frequency locked-loop (PLL/FLL) type or direct digital synthesizer (DDS) type, followed by an associated alignment circuit 3000.

Since the radiofrequency band used for these devices may be very broad, the progression of the amplitude of the signal 2a output by the generator 2 may vary with variation of the frequency within the operating band as shown in Figure 10.

By means of the process according to the invention applied to an alignment circuit 3000 whose amplitude can be calibrated, it is possible to compensate automatically for the variations which occur at the different frequencies, obtaining a progression of the output amplitude of the alignment circuit upon variation of the frequency as schematically shown in Figure 11.

As in the case above, the calibration procedure will maintain a constant value for preselection of the variable amplifier and the attenuator and will adjust exclusively equalization. The automatic calibration system will then supply the control parameters thus determined to the alignment circuits and these will be stored in the module memory.

It is therefore clear how, with the automatic calibration and test process according to the invention, it is possible to calibrate the alignment circuits for wideband microwave modules in an automatic, reliable and fast manner, thus providing a solution to the said problems of lack of precision, repeatability and stability arising from the calibration procedures of the prior art, resulting in calibration

which is independent of the specific technical ability of the test personnel and achieving a substantial reduction in cost.

Although described in connection with certain constructional forms and certain preferred examples of embodiment of the invention, it is understood that the scope of protection of the present patent is defined solely by the following claims.

## CLAIMS

1. Process for automatically calibrating, according to pre-defined specification values of a plurality of calibration parameters (Gm-min-spec; Gm-max-spec;  $T_i$ ;  $V_i$ ;  $B_i$ ), a wideband microwave module comprising at least one basic alignment circuit each comprising at least one filter, followed by at least one variable amplifier, by a variable attenuator and by a variable equalizer, the voltage input/s of which can be controlled, being supplied with frequency signals lying within different bands ( $B_i$ ) and operating at different temperatures ( $T_i$ ), and for which at least the following calibration parameters have been defined according to specification values:

- temperatures  $T_1, T_2, \dots T_i$  at which test cycles of the automatic calibration cycle must be performed;
- nominal start-of-procedure input voltages ( $V_{1i}, V_{2i}, V_{3i}, V_{4i}, V_{5i}, V_{6i}, V_{7i}$ );
- Gm-max-spec = Maximum gain of the alignment circuit/s, according to specification, for each band;
- Gm-min-spec = Minimum gain of the alignment circuit/s, according to specification, for each band;

there being provided an intermediate frequency conversion block, which performs conversion to the intermediate frequency of the signal incoming from the alignment circuit/s and which has an output;

characterized in that it comprises the following steps:

20) initial configuration of a PLC controller with storage of the said start-of-procedure input voltages ( $V_{1i}, V_{2i}, V_{3i}, V_{4i}, V_{5i}, V_{6i}, V_{7i}$ ) in a static memory of the PLC controller itself;

30) automatic application of the said start-of-procedure input voltages ( $V_{1i}, V_{2i}, V_{3i}, V_{4i}, V_{5i}, V_{6i}, V_{7i}$ ) to the respective input points of the respective amplifier/s, attenuator/s, and equalizer/s of the basic alignment circuit/s ;

31) introduction, into the PLC memory, of pre-defined values of calibration parameters of the calibration cycle which are specific for

each microwave module to be calibrated and comprise at least:

- the number  $N_B$  of bands ( $B_i$ ) of the microwave module to be calibrated; there being provided three frequency sub-bands, plus one direct band;
- the temperature values  $T_i$  at which the test cycles of the calibration cycle are to be performed;

40) CALIBRATION CYCLE upon variation of the temperature:

41) for each pre-defined temperature  $T_i = T_1, T_2, T_3$

42) setting the temperature of the microwave module to the test temperature  $T = T_i$ ;

50) Calibration of the variable equalizers of the at least one basic alignment circuit for each band for which the microwave module must operate;

51) application of a test signal to the input of an input block connected to an antenna for each frequency band ( $B_i$ ) of the signals input into the module;

51a) measurement of the slope of the gain of the alignment circuit or of the slope of the amplitude of the signal in the band  $B_i$  at the output of the intermediate frequency conversion block,

52) COMPARISON between the slope measured and a characteristic slope of a design specification:

52a) slope measured > slope of the design specification?

YES-> reduction of the slope of the operating band ( $B_i$ ) by suitably modifying the voltages ( $V_6$ ) and ( $V_7$ ) applied to respective adjustment points of the equalizer for the band ( $B_i$ ); and repetition of the comparison cycle (51a, 52, 52a;52b) ;

NO->

52b) slope measured < slope of the design specification?

YES-> increase of the slope of the operating band ( $B_i$ ) by suitably modifying the voltages ( $V_6$ ) and ( $V_7$ ) at the respective adjustment points of the equalizer for the band ( $B_i$ ); and repetition of the comparison cycle (51a, 52, 52a;52b);

NO->

53) repetition of the cycle (51-52) for each band ( $B_i$ ) of the input signals;

70) Calibration of the amplifier/s and the attenuator/s of the basic alignment circuit/s;

71) for each frequency of the bands ( $B_i$ );

72) measurement of the average gain ( $G_{m1}, G_{m2}, \dots, G_{mNB}$ ) of the transfer function of the microwave module between the input of the input block and the output of the frequency conversion block;

73) calculation of the value  $G_{m-max} = \max(G_{m1}, G_{m2}, \dots, G_{mNB})$ ;

74) calculation of the value  $G_{m-min} = \min(G_{m1}, G_{m2}, \dots, G_{mNB})$ ;

75) comparison between  $G_{m-max}$  and the specification value  $G_{m-max-spec}$ ;

75a)  $G_{m-max} > G_{m-max-spec}$ ?

YES-> the amplification is decreased and the attenuation is increased in the basic alignment circuit for the band  $B_i$  corresponding to  $G_{m-max}$  by adjusting the input voltage ( $V_1$ ) of the associated amplifier/s and the input voltage/s ( $V_4, V_5$ ) of the associated attenuator/s;  
repetition of the cycle (72,73,74,75+75a);

NO->

76) Comparison between  $G_{m-min}$  and the specification value  $G_{m-min-spec}$

76a)  $G_{m-min} < G_{m-min-spec}$ ?

YES-> the amplification is incremented and the attenuation is decreased in the basic alignment circuit for the band ( $B_i$ ) corresponding to  $G_{m-min}$  by adjusting the input voltage ( $V_1$ ) of the associated amplifier/s and the input voltage/s ( $V_4, V_5$ ) of the associated attenuator/s;  
repetition of the cycle (72,73,74,75,76,76a);

NO->

80) Storage of the values of the said adjusted input voltages ( $V_1, V_4, V_5$ ) corresponding to respective values of the temperature ( $T_i$ )

in the memory of the PLC;

- 90) Repetition of the entire cycle for each temperature (Ti).
- 140) Start of an automatic test procedure;
- 150) Generation of a test sheet of the microwave module.

2. Process according to Claim 1, characterized in that said start-of-procedure voltages values are obtained by a preliminary PROTOTYPE CHARACTERIZATION step involving tests on a calibration bench and alignment performed on prototypes of the module.

3. Process according to Claim 1, characterized in that it comprises the steps of compensating the maximum output power and the average value of the gain of the intermediate frequency conversion block within the entire operating band, before the signal is sent to the output for subsequent processing, said intermediate frequency conversion block being part of the wideband microwave module.

4. Process according to Claim 3, characterized in that it comprises a step for definition, according to specification, of the following parameters:

- $G_{tot-m-spec}$  = Total average gain, according to specification, of the module.

5. Process according to Claim 4, characterized in that it comprises the further steps of:

60) Calibration of the amplifiers and the attenuators of the common intermediate frequency conversion block;

61) measurement of the average gain  $G_{tot-m}$  in the entire operating band between the input and the output of the module;

62) Comparison with the pre-defined specification value  $G_{tot-m-spec}$

62a)  $G_{tot-m} > G_{tot-m-spec}$ ?

YES-> the amplification is decreased and the attenuation of the intermediate frequency conversion block is increased and the comparison repeated;

NO->

62b)  $G_{tot-m} < G_{tot-m-spec}$ ?

YES-> the amplification is increased and the attenuation of the intermediate frequency conversion is decreased and the comparison repeated

NO->

6. Process according to Claim 3, characterized in that it comprises the further steps of

100) Measurement of the Noise Figure (NF) for each of the operating bands (Bi);

110) Comparison between the measured Noise Figure value  $NF_m$  and a pre-defined Noise Figure value  $NF_{spec}$  of the specification;

110a)  $NF_m$  not to the pre-defined value of specification?

YES->increase in the gain of the input preamplifier;  
repetition of the entire calibration cycle for all the temperatures  $T_i$ ;

NO->

120) Measurement of the linearity of the transfer function between the input and the output for each of the bands (Bi);

130) Comparison between the linearity measured and the pre-defined values of specifications

130a) Linearity not to the pre-defined values of specification?

YES-> increase in the attenuation of the input stage;  
repetition of the entire calibration cycle for all the temperatures ( $T_i$ )

NO->

140) Start of the automatic test procedure.