A NEW CALIBRATION CONCEPT FOR INSTRUMENTATION TAPE RECORDERS

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ABSTRACT:

A new calibration concept for instrumentation tape recorders which insures consistent data quality is presented. This technique utilizes a single composite signal for complete amplitude and phase equalization of direct reproduce data electronics. In addition, the method permits equalization for tapes recorded with analog or saturation record electronics, and also permits calibration at different reproduce tape speeds from a single recorded preamble.

The composite signal description and block diagram of the generation-measurement equipment are presented along with system test results.

INTRODUCTION:

Magnetic tape recorders are used in applications requiring storage of large amounts of analog or digital data because the magnetic tape storage medimum is relatively inexpensive. The data quality, however, depends upon the tape-head interface which is subject to record side calibration, head wear, tape variations, and crossplay problems when two or more transports are used. Previously, taped data quality problems have been reduced by “Auto Test” functions. Although these functions can determine if a data channel was not operating properly, they could not automatically correct for calibration errors.

By providing computer adjustment capability in the data cards, and additional computer support in the measurement system, automatic calibration can be accomplished. System performance can be further enhanced if a single calibration signal can be selected to measure specific equalizer amplitudes as well as phase equalization for bias as well as non bias recorded formats. Since a single signal would simultaneously contain all of the reproduce calibration information, it would also be tape speed independent.

CALIBRATOR SIGNAL DESCRIPTION:

Development of a calibration signal requires examination of the basic tape recorder transfer function shown in Figure #1. At low frequencies, the reproduce amplitude increases at +6dB per octave due to the transformer function of the reproduce tape head. At high frequencies, various signal losses reduce the efficiency of the tape head causing a reduction of signal output.

One way of equalizing this response is to use three equal and opposite analog functions, shown in Figure #2, which are uniquely adjusted for each tracks needs. The integrator compensates low frequencies with a −6dB per octave amplitude vs frequency slope. The integrator’s 0.2BE break point allows the peak of the head curve to be passed without change, and the bandedge (BE) peaking function compensates for high frequency losses. The result, when equalized properly, is a data channel with an equal amplitude response at all frequencies within the tape recorder’s bandpass as shown in Figure #3. Since these three equalizing functions are dependent on tape velocity, the absolute frequency of these calibration parameters is linearly dependent on tape speed.

The signal shown in Figure #4 is ideal for calibrating these reproduce equalizers because it has known frequency components corresponding to the end points of the three equalizing parameters described above. In addition, the signal is recorded with a constant wavelength on tape to accommodate calibration at different reproduce tape speeds utilizing a single recorded preamble. Saturation (non bias) head drivers are accommodated by the bi-level property since the amplitude and phase components of the calibration signal would not be distorted in an amplitude limited system.

The basic building block is a 7 state puesdo-random sequence (PRN) shown in Figure #5. Figure #5a is the “time domain” representation as observed on an oscilloscope, and Figure #5b is the “frequency domain” representation as observed an a spectrum analizer. By choosing the proper clock rate on a PRN sequence generator, the fundamental frequency component can be located near the integrator 0.2BE equalizer breakpoint. The third harmonic would then be located at 0.6BE, and the fifth harmonic at the bandedge frequency. Additional higher order harmonics are beyond the equalizer’s frequency response and therefore not reproduced. Since the second and the fourth harmonics are not necessary, half wave symetry is employed in Figure #6a to eliminate the even harmonics, and enhance the odd harmonics.

The fourth component, the low frequency component, can be added to the combination 0.2BE, 0.6BE, and BE signals by interupting the PRN sequence and alternately inserting a string of all logic ones later followed with a string of all logic zeros. Figure #7a shows how this adds a periodic DC offset at a rate corresponding to the desired low frequency component. The discrete nature of the low frequency component provides multiple odd harmonics in the frequency spectrum shown in Figure #7b. (The PRN period has been reduced in Figure #7a to allow representation in reasonable space.)

The total calibration signal, previously shown in Figure #4, has the time representation of Figure #6a combined with Figure #7a. Similar to the time representation, the frequency spectrum shown in Figure #6b can be combined with the frequency spectrum shown in Figure #7b to produce the total frequency spectrum shown in Figure #8.

At high and medimum speed calibrations, the lowest low frequency component is used. A preamble recorded at these speeds, and subsequently reproduced at the lowest tape speeds requires the third or the fifth harmonic of the low frequency component since these frequencies are above the the equalizers lower band edge frequency response.

To summarize, the calibration signal contains all frequency components with known amplitude and phase necessary to perform the calibration of direct reproduce equalizers. Since three low frequency components are always included, the same calibration signal can be used even at the lowest tape speeds where the constant equalizer lower bandedge frequency requires a proportionately higher low frequency. Simultaneous or individual measurements of low frequency, 0.2BE, 0.6BE, BE, and phase are possible at any time because all measurement frequencies are simultaneously available. This is an important factor when a calibration signal is recorded at high tape speeds and reproduced at low tape speeds or visa versa since a search for the proper frequency is not necessary.

Digital systems utilizing saturation head drivers are becoming more prevalent. Since the calibration signal is bi-level, the recording method is not a factor in the calibrator’s operation.

CALIBRATION SIGNAL GENERATOR IMPLEMENTATION:

The calibration signal generator synthesizes the calibration signal at frequencies corresponding to the selected tape speed. The diagram shown in Figure #9 blocks out the the hardware required to generate a calibration signal with high amplitude and frequency accuracy.

A crystal oscillator provides an ideal clock source for the calibration signal generator since it insures good frequency stability. The proper clock rate for the calibration signal generator is 2.8 times the maximum bandedge frequency because the fundamental 0.2BE component is 1/14 of the clock rate, and the bandedge component is the 5 th harmonic of the 0.2BE component. The binary clock divider is used to reduce the shift register clock rate for lower tape speeds.

The calibration signal generator can be divided into three sections. First, the shift register is connected to exclusive OR gates to form a PRN generator. The second exclusive OR gate provides half wave symmetry to eliminate even harmonics. Second, the divide by 10 counter increments by one after every PRN period to enable the insertion of the low frequency component. The toggle flipflop completes the low frequency component after 20 periods of the PRN sequence which adds a 1/100 bandedge low frequency signal. The last section is a selector which gates 9 PRN sequences, followed by a sequence of all logic ones, followed by 9 more PRN sequences, and ended by a sequence of all logic zeros controlled by the toggle flipflop output. The result is the calibration signal shown previously in Figure #4.

Figure #10 is an actual frequency spectrum of the calibration signal. The periodic DC offset produces multiple low frequency components throughout the spectrum. Since the low frequency component periodically replaces the 0.2BE, 0.6BE, and BE components, these frequencys are amplitude modulated by the repetition rate of the alternate ones and zeros used to generate the low frequency signal. These side bands have little effect on the calibration ability of calibration signal because they have a much lower amplitude than the 0.2BE, 0.6BE, and BE signals.

MEASUREMENT SYSTEM IMPLEMENTATION:

The measurement system must lock onto the reproduced calibrator signal, and select the required component (or components) for the desired measurement. The block diagram shown in Figure #11 outlines the measurement system’s three sections. The first section contains an automatic gain control (AGC) to conditions the incoming signal and phase locked loop #1 (PLL 1) locks onto the 0.2BE component. The first section also contains a calibration signal synthesizer for phase measurements, similar to the signal generator described in the signal generator section, with the 0.2BE component locked in phase quadrature with the reproduced calibration signal.

The second section uses the 0.2BE signal from the first phase locked loop and generates a first, third, or fifth harmonic frequency with a small offset frequency. Figure #12b shows the specific case of the 0.6BE frequency plus 1 K Hz. When this signal is mixed with the incoming signal in the double balanced mixer shown in Figure #12a, the sum and difference terms are generated as shown in Figure #12c. The low pass filter retains the difference term which is converted into digital form by the RMS converter and the A/D converter. This same method is also used to measure the low frequency components, 0.2BE, and BE components.

Phase measurements utilize the phase detection capability of the double balanced mixer. Figure #13a shows the calibration signal synthesizer output with its 0.2BE component in phase quadrature with the input signals 0.2BE component. Since this signal synthesizer is similar to the generator, its 0.2BE, 0.6BE, and BE components have the same relative amplitude, and phase as the generator used to make the recording.

When the incoming and the synthesized signals are mixed in the double balanced mixer, the 0.2BE components produce zero output since they are in phase quadrature. Figure 13b shows how the combined phase error of the 0.6BE, and BE components relative to the 0.2BE component produce a DC offset at the mixer output. Similar to the 0.6BE measurement described above, the low pass filter retains the DC offset which is converted into digital form by the rms converter- and the A/D converter.

SOFTWARE MEASUREMENT ALGORITHMS

Software algorithms are necessary to interpret the individual component levels of the calibration signal. The flow chart shown in Figure #14 illustrates the relative method used for all measurements. When a measurement is requested, the measurement system must first be calibrated to the new component level. This function starts in the flow chart's "reference process" where the measurement system is reconfigured for the new measurement and connected directly to the signal generator. The following measurement is saved in the reference register to be later used in the program, "measurement process". Since the "end measurement" decision should be "No" the first time through, the program will continue to the "measurement process". In the "measurement process", the calibrator is connected to the data channel output, and the same component is again measured and stored in the data register. The measured data value is then divided by the reference value to obtain the actual gain of the selected frequency component. In other words, the measurement system measures the actual gain (or attenuation) of the specified signal component through the data channel, not its absolute amplitude.

To support data channel calibration conventions, the component gain value is normalized to 1 Vrms and displayed. This means that if a constant signal of 1 Vrms was applied to the input, the reproduced signal output value would correspond to the displayed value. Since the calibrator measures the signal output relative to the actual signal input, amplitude drifts in the generator do not affect the measurement accuracy.

Once accurate measurements can be made at the specified equalizer adjustment points, other computer algorithms can be devised to adjust the data cards to the desired specification without operator intervention.

The flow chart shown in Figure #15 shows a method for performing auto calibration. Initially the equalizer's gain (measured with the calibration signal's low frequency component) is compared to the calibration criterion which is usually 1 Vrms. If this signal is outside of the selected amplitude error limits, program execution branches to a gain adjustment algorithm which controls the data cards digital to analog converter (DAC) in a logical direction to minimize the calibration error.

If the signal is within the selected amplitude error limits, program execution continues to the 0.2BE test where the same process is repeated with the 0.2BE calibration component. If this signal is within it’s amplitude error limits, no changes will be made. If the amplitude error exceeds the value specified in the calibration criterion, the 0.2BE adjustment path will minimize the error. Since reproduce equalizer adjustments are interactive, that is one adjustment can affect other adjustments, program election must branch back to the gain test whenever any other adjustment changes are made.

After all of the interactive adjustments are made correctly, program execution continues to the phase adjustment. Similar to the other calibration procedures, this procedure iterates until the phase measurement is within the limits specified by the calibration criterion.

TEST DATA:

Figure #16 shows the bench set-up used to automatically test calibrator performance. Although the Model-97 calibrator system performs all required FM, and direct measurements for both record and reproduce electronics, only the test data pertinent to the direct reproduce calibration signal and associated hardware is presented.

A calibrator versus external test equipment program was devised by connecting IEEE-488 compatible test equipment to the Model-97, and using a desk top computer as a combined controller, calculator, and data logger. The test program requests the calibrator and the external test equipment to measure all reproduce parameters (with the exception of phase) at all reproduce speeds. Phase was measured by the calibrator and recorded in the last column. Since dropouts can cause measurement errors in both internal and external test equipment, five readings were taken and averaged. The results are then compared in the desk top computer, and printed for evaluation. As illustrated in Table I, all measurements were usually within +/− 1 dB which is well within the +/− 3dB data channel specification.

The phase desplay reads zero when the phase of the reproduced 0.2BE, 0.6BE, and BE components matches the phase of the synthesized calibration signal since the DC offset previously described in the measurement section will be minimized. If a reproduce channel has not been adjusted for optimun phase responce, the phase measurement will have a positive, or negative value proportional to the magnitude and dirrection of the phase error. A zero desplay indicates an optimum phase response in the data channel. Values between +10, and −10 indicate an acceptable phase response.

CONCLUSION:

The combined signals calibation signal method described here greatly reduces the complexity of signal generation, and computer support of an automatic calibration system. This is primaraly due to the calibration signal's bi-level construction, and because it simultaneously contains all reproduce calibration signals.

Assuming a measurement system would be required to measure phase and therefore need circuitry similar to phase locked loop #1, the only additional hardware complexity necessary for this calibration method is the phase locked loop #2 measurement circuitry. Other calibration methods utelizing sine wave synthesizers with a wideband rms converter would not require this circuitry, but must be designed to operate over a much wider operating frequency since they don't have the capability of converting all calibration frequencies to 1 KHz. This type of system would also have the additional complexity of searching for and identifing the proper calibration frequency.

The Model-97 uses the combined calibration signal for direct calibration because it streamlines the automatic reproduce calibration procedures thereby insuring consistently good data quality. In addition, it provides the tape system designer with a single reproduce calibration preamble usable at all tape speeds on bias as well as nonbias recording equipment.

TABLE I: Calibration system measurement accuracy

Speed	Gain	0.2BE	0.6BE	BE	Phase
---------	---------	---------	---------	---------	---------
240 ips	0.05dB	0.09dB	−0.16dB	−0.19dB	−1
120	0.14	0.15	−0.01	0.12	−1
60	0.26	0.14	0.04	0.09	−1
30	0.07	0.05	−0.03	−0.19	−1
15	0.22	0.07	−0.09	−0.23	−1
7.5	0.15	0.14	−0.07	−0.17	−7
3.75	0.36	0.13	−0.11	−0.21	−3
1.87	0.03	0.28	−0.11	−0.28	−4
.937	0.37	0.16	−0.03	−0.23	−2

Figure #1:
Reproduce Signal vs
Frequency Characteristic

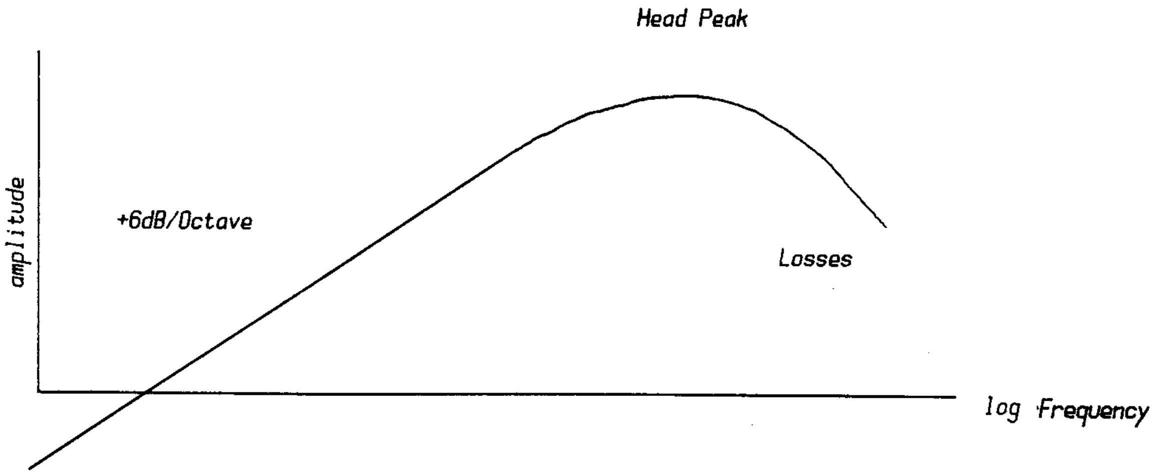


Figure #2:
Equal and Opposite
Reproduce Electronics
Characteristic

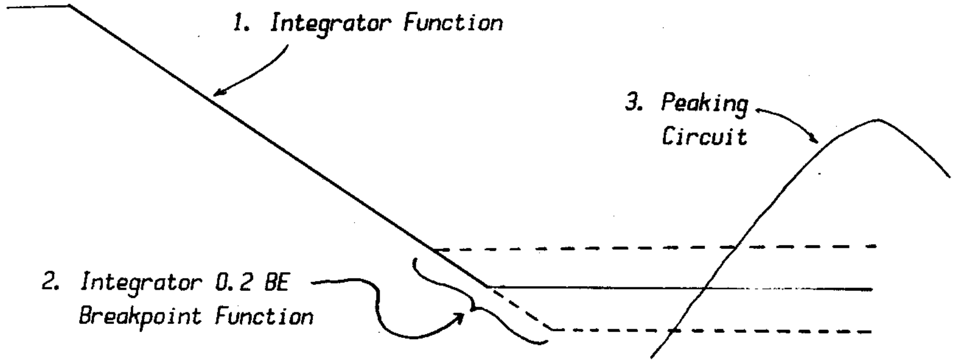


Figure #3:
Data Channel
Bandpass Response

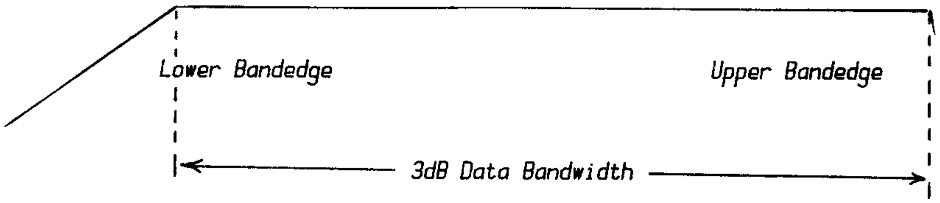


Figure #4:

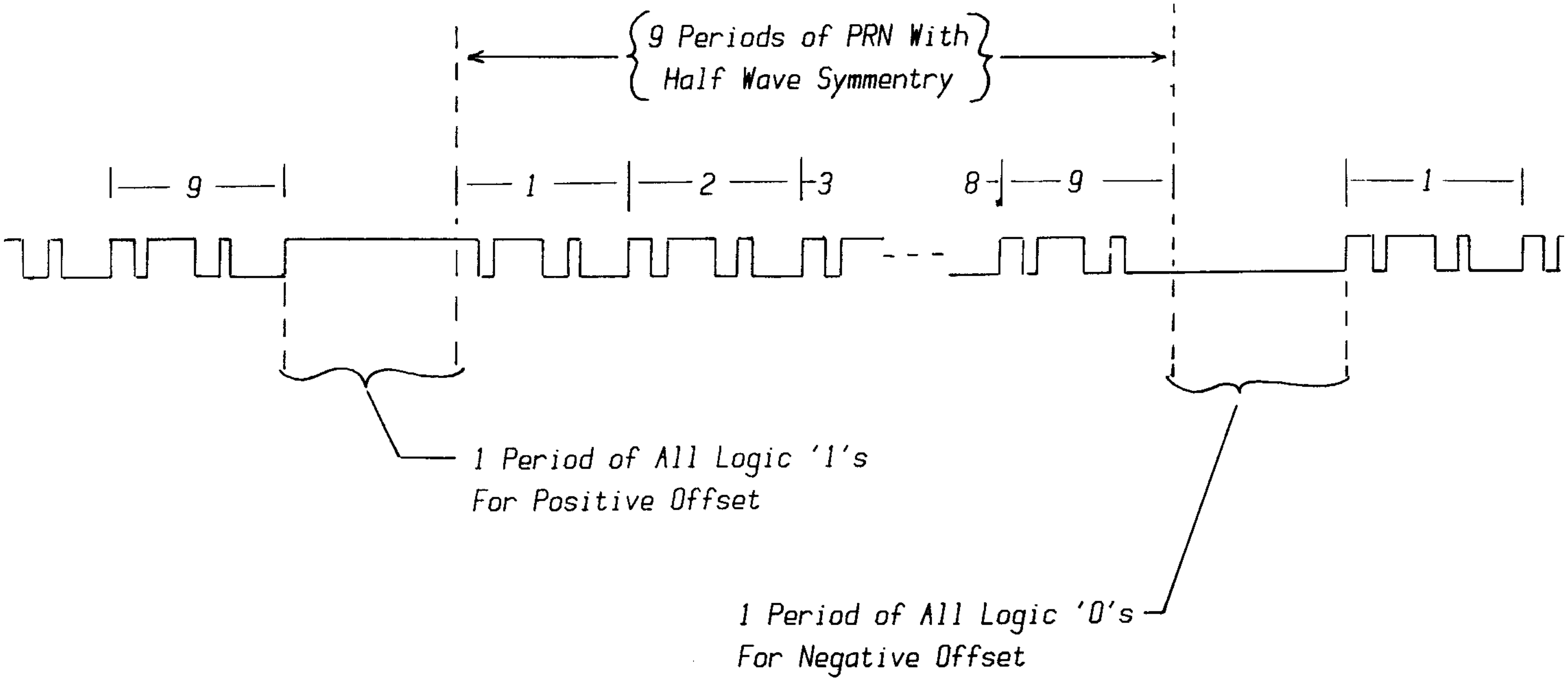
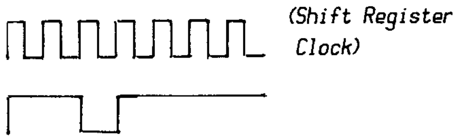

9 Periods of PRN With Half Wave Symmentry
9
1
2
3
8
9
1
1 Period of All Logic '1's For Positive Offset
1 Period of All Logic '0's For Negative Offset

Figure #5a:

(2^3-1) PRN



Amplitude vs Frequency Spectrum

Figure #5b:

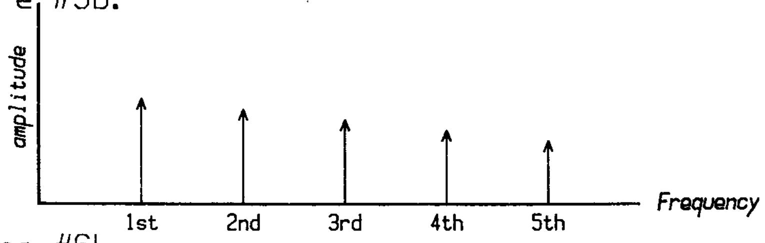


Figure #6a:

(2^3-1) PRN With
Halfwave Symmetry

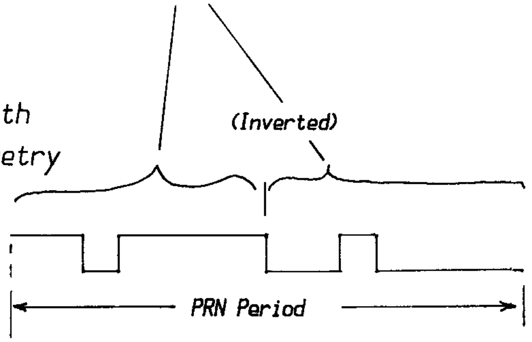


Figure #6b:

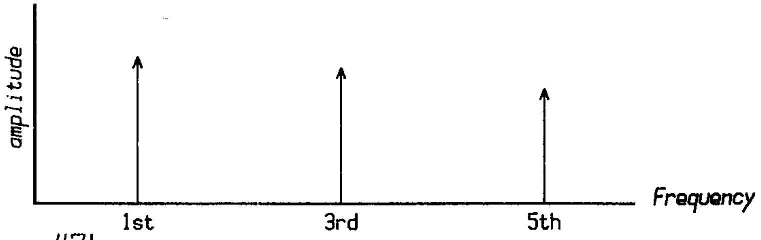


Figure #7a:

Low Frequency Component

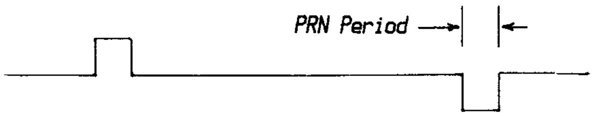


Figure #7b:

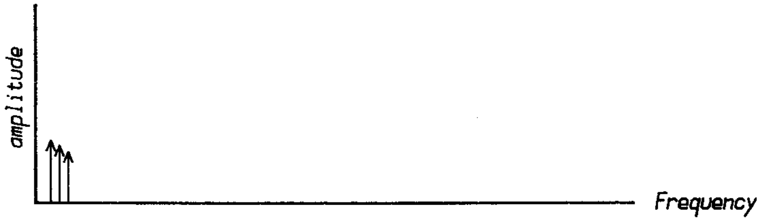


Figure #8:

Total Calibration Signal

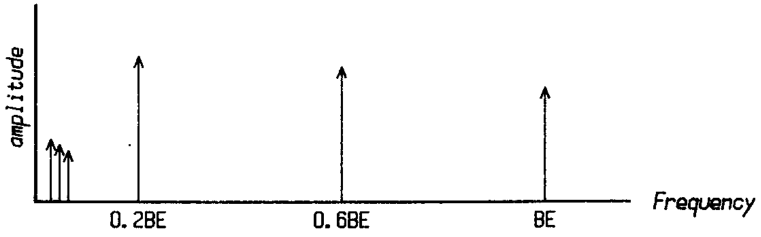


Figure #9: Calibration Signal Generator

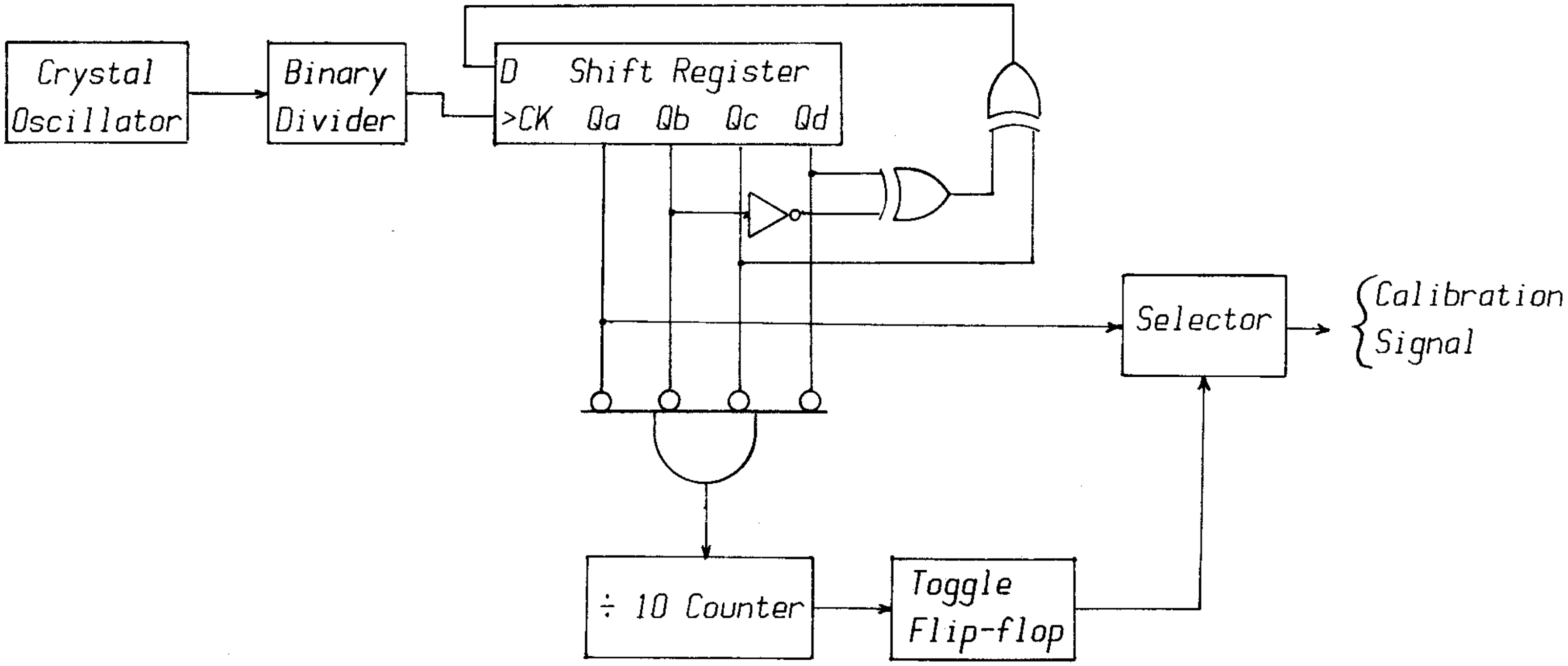


Figure #10 :

Actual Frequency Spectrum of Calibration Signal

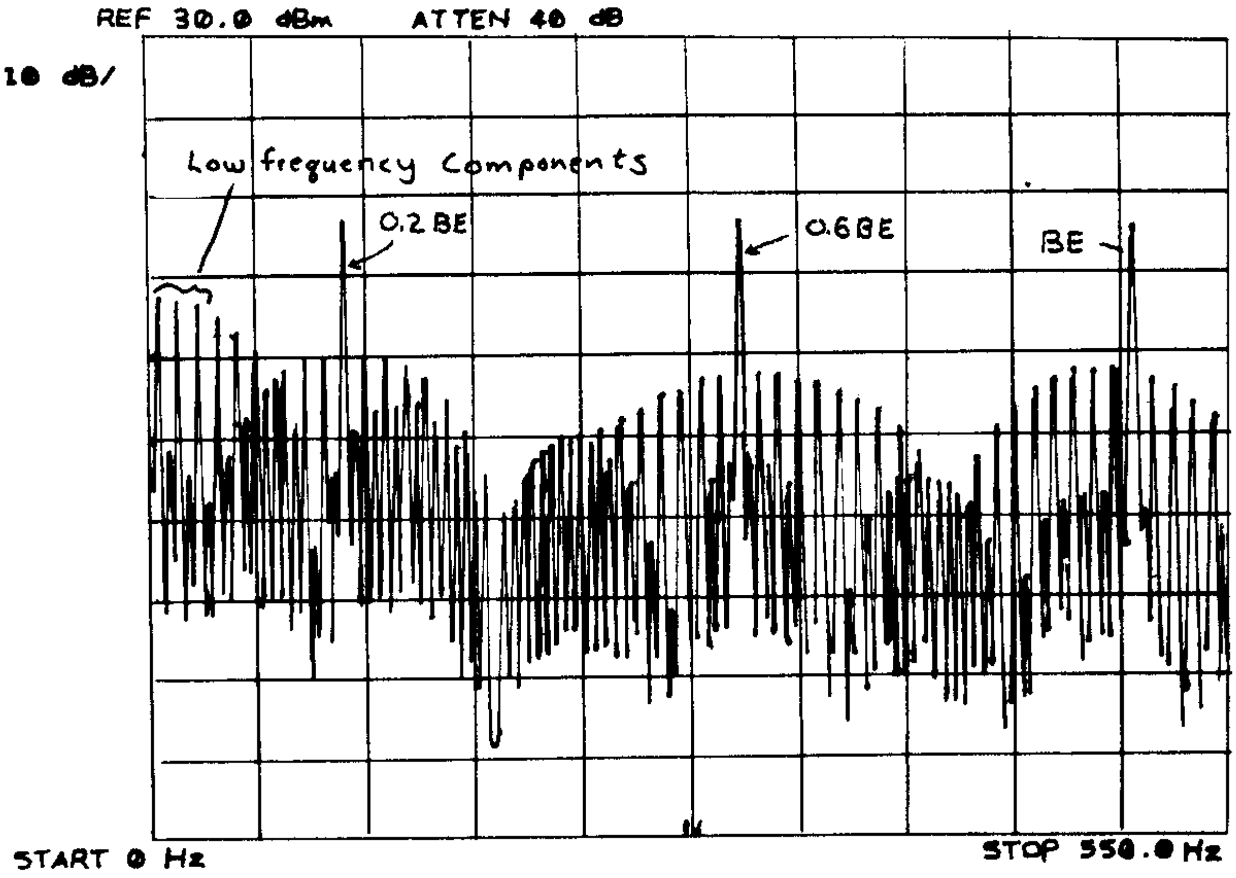


Figure #11:
Measurement System

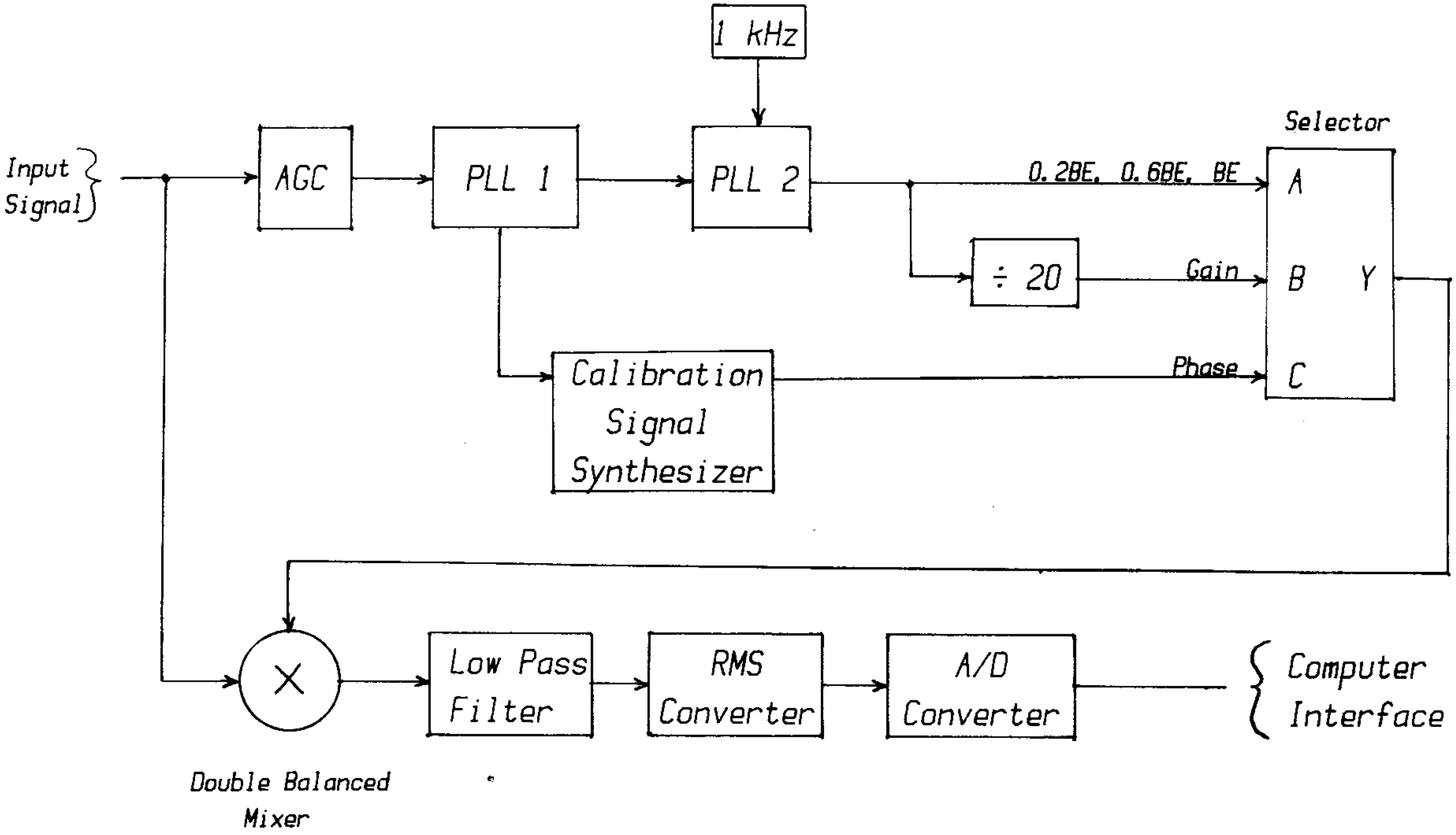


Figure #12a:
Calibration Input Signal

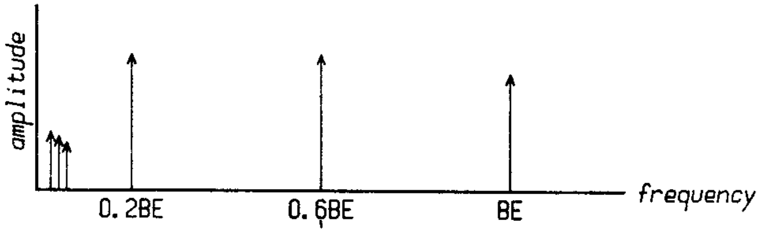


Figure #12b:
0.6BE Amplitude Measurement

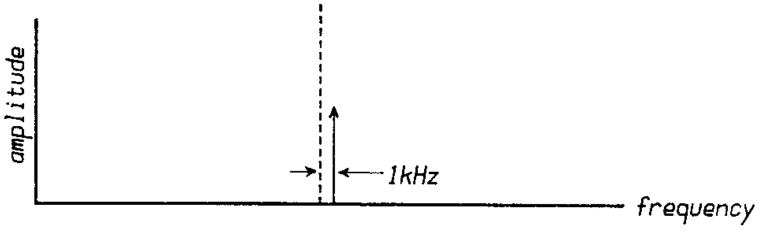


Figure #12c:
Filtering of Difference Term

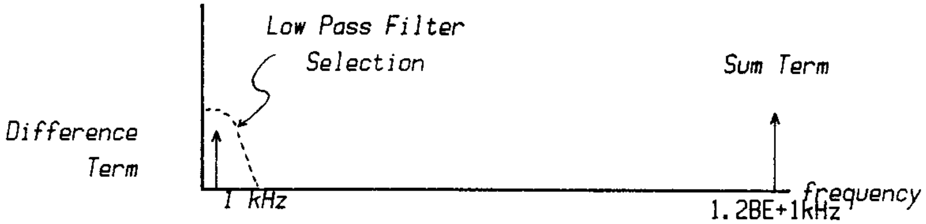


Figure #13a:
Synthesized Calibration Signal

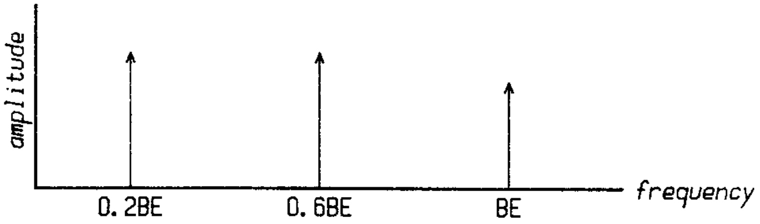


Figure #13b:
Filtering of Phase Term

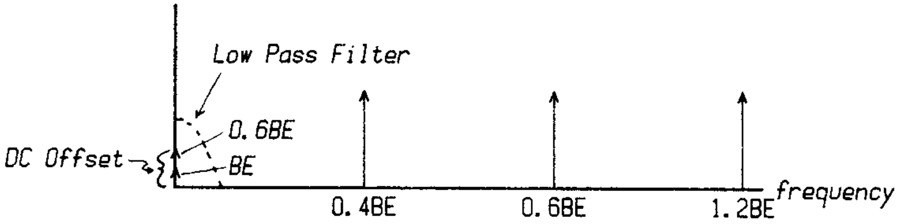


Figure #14:

Calibration
Signal
Measurement
Process

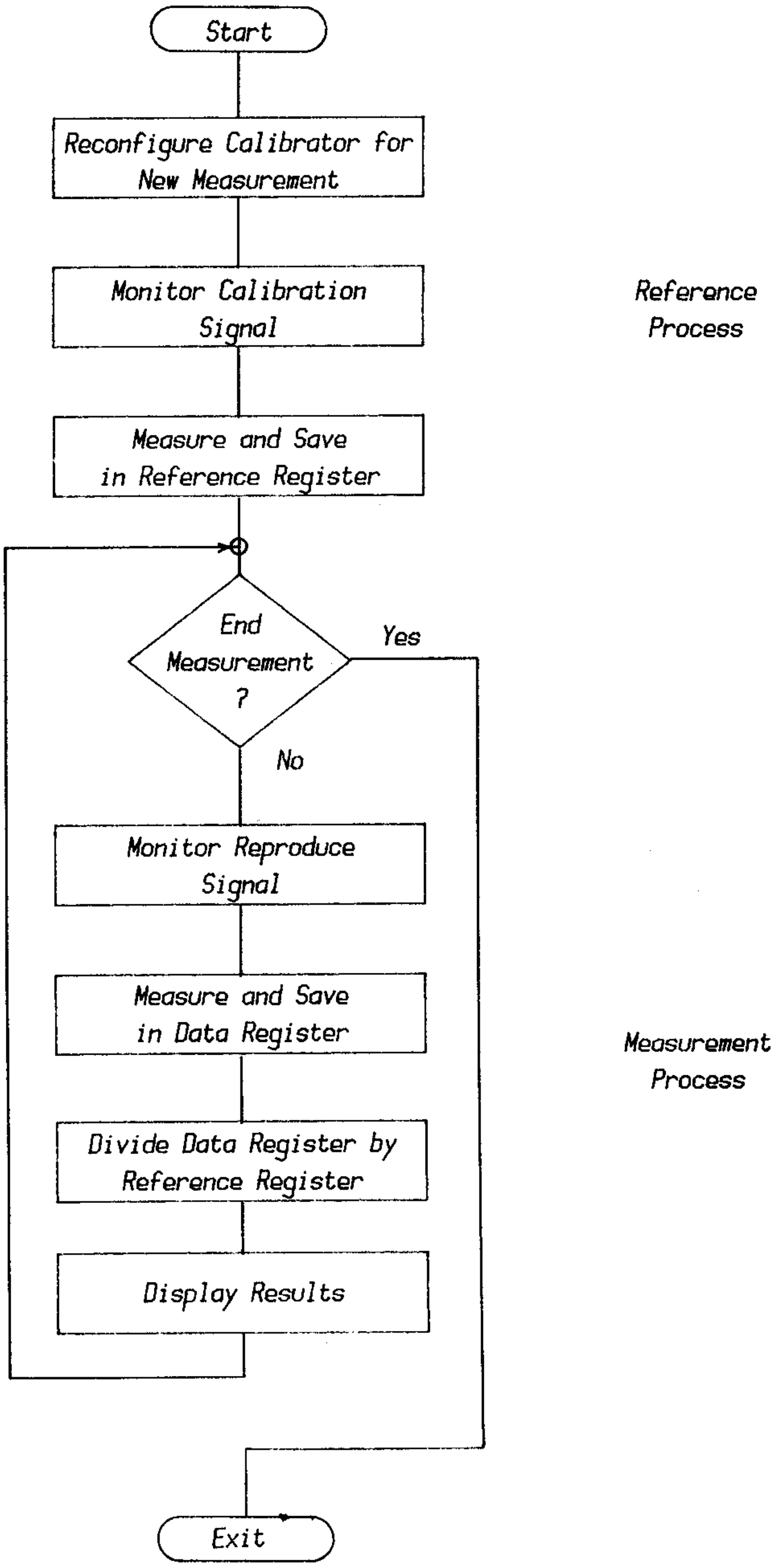


Figure #15:
Automatic
Calibration
Procedure

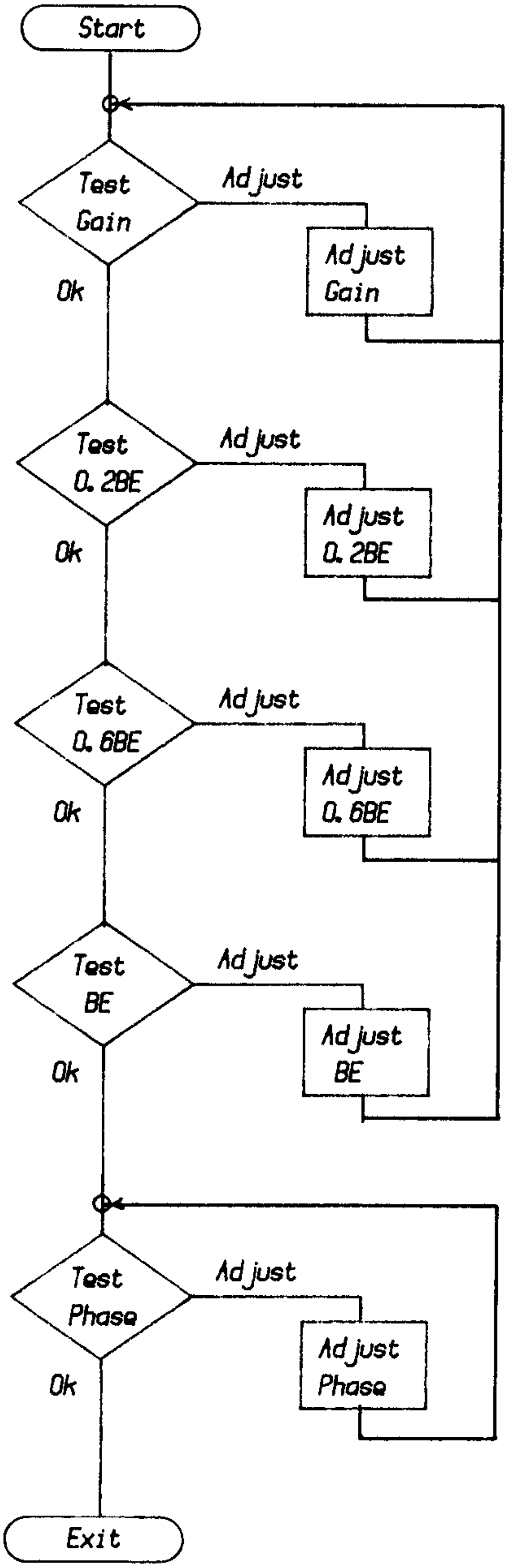


Figure #16
Model-97