Model 599
Loss Free Counting Module

User's Manual

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SYSTEM
CERTIFIED

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Canberra Industries, 800 Research Parkway, Meriden, CT 06450
Tel: 203-238-2351 FAX: 203-235-1347 http://www.canberra.com

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1. Introduction

The Model 599 Loss Free Counting (LFC) module provides the ability of performing real-time correction of system counting losses. This feature is particularly useful when measuring short-lived radionuclides, stack emissions, or any measurements where spectral distribution is changing. LFC can also be used to obtain significant improvements in the live time accuracy of the spectroscopy system.

LFC provides the capability of dynamically adding the fractional counting losses to the spectrum as they occur in real times, rather than extending the measurement duration as in live time correction. Several techniques for computing the short term counting losses have been implemented and can be selected by the user.

The 599 is compatible with most Canberra MCAs. The MCA and ADC must be equipped with the standard 34-pin ribbon cable connections to allow the LFC module to plug in directly.

To achieve maximum throughput rate, the MCA must be equipped with a READ-ADD-N function (consult the factory for information about a specific MCA), that allows the MCA to add numbers 1 to 255 to the contents of a channel. Without this feature, multiple READ-ADD-1 memory cycles must be performed for each event, thereby limiting the system throughput rate.

The accuracy of the results obtained with either mode is the same; over a range of input rate to 50 kHz. If detector input rates in excess of 50 kHz are expected, the MCA should be equipped with the READ-ADD-N option. An internal jumper in the 599 selects the transfer mode.

Dual LFC Option

The Dual LFC option allows accumulation of a loss-free corrected spectrum simultaneously with an uncorrected spectrum. Analysis of the two spectra together allows more accurate quantification of the data than analysis from a single spectrum. (Refer to Appendix E for details on the Dual LFC option.)

Peak centroid (energy), net area, background and counts per second are computed from the corrected spectrum, while the uncertainty in the computed peak area is derived from the uncorrected spectrum. This results in a better estimate of the error than if the computation were performed using the corrected spectrum (due to the non-Poisson nature of the corrected spectrum).

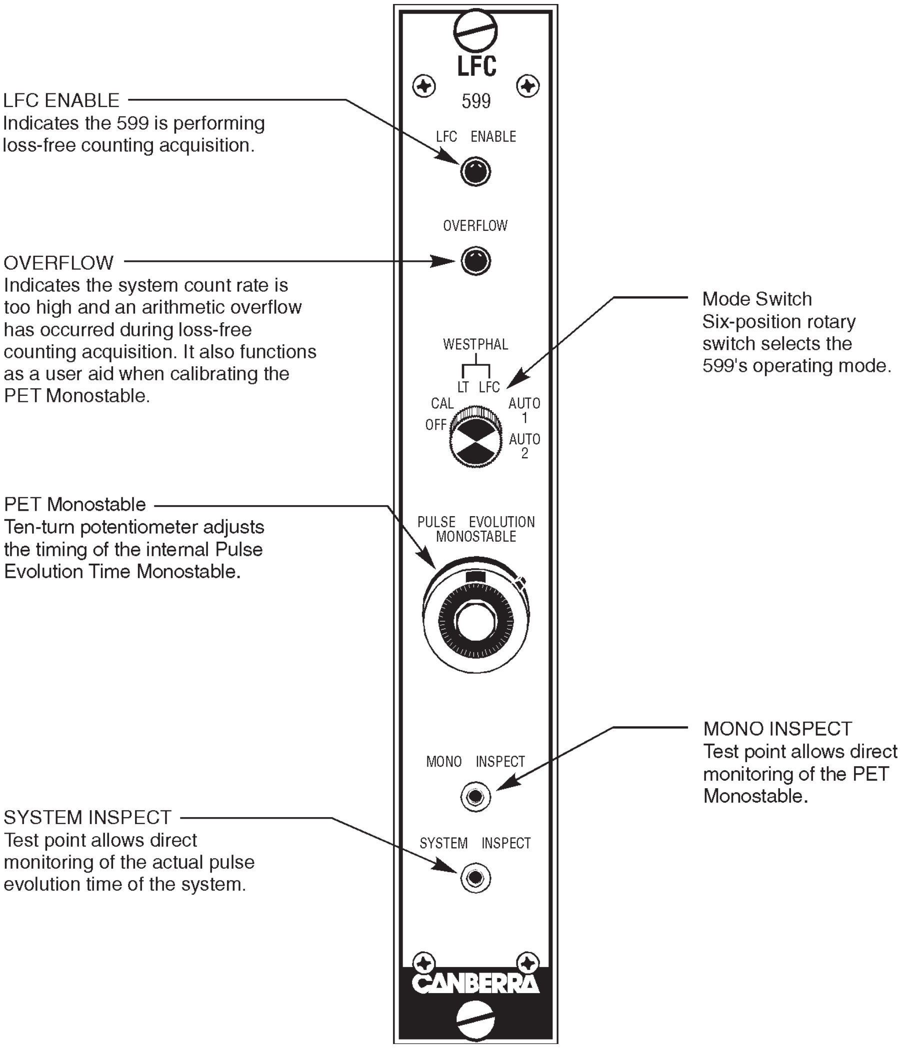
To use the Dual LFC Mode, a contiguous band of MCA spectral memory must be allocated which is equal to twice the desired spectrum size.

Additional analysis software required to quantify the tandem spectra is contained in the Model 480198 VMS Spectroscopy Applications software. Additional analysis software, such as the Model 480201 VMS Nuclide Identification software, may be required, depending on the application.

2. Controls and Connectors

Front Panel

This is a brief description of the 599’s front panel controls and connectors. For more detailed information, refer to Appendix A, Specifications.



LFC ENABLE
Indicates the 599 is performing loss-free counting acquisition.

OVERFLOW
Indicates the system count rate is too high and an arithmetic overflow has occurred during loss-free counting acquisition. It also functions as a user aid when calibrating the PET Monostable.

PET Monostable
Ten-turn potentiometer adjusts the timing of the internal Pulse Evolution Time Monostable.

SYSTEM INSPECT
Test point allows direct monitoring of the actual pulse evolution time of the system.

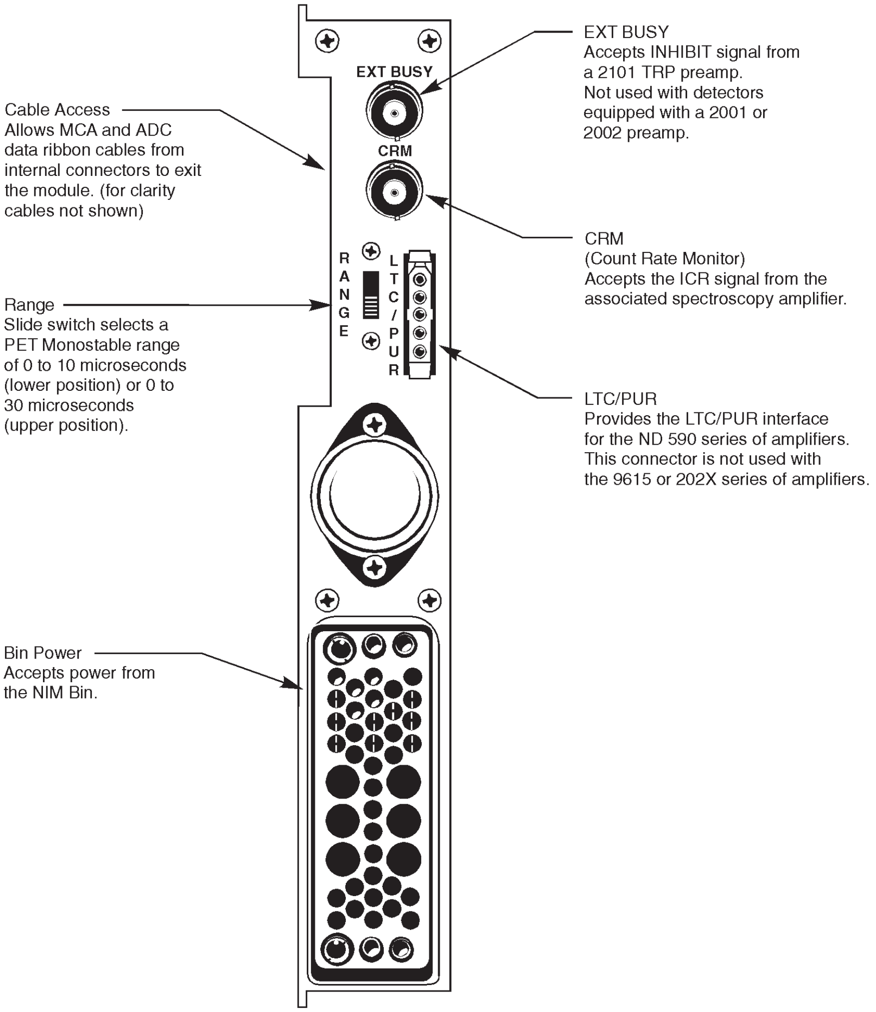
Mode Switch
Six-position rotary switch selects the 599's operating mode.

MONO INSPECT
Test point allows direct monitoring of the PET Monostable.

Figure 1 Front Panel Controls

Rear Panel

This is a brief description of the 599’s rear panel connectors. For more detailed information, refer to Appendix A, Specifications.



Cable Access
Allows MCA and ADC data ribbon cables from internal connectors to exit the module. (for clarity cables not shown)

Range
Slide switch selects a PET Monostable range of 0 to 10 microseconds (lower position) or 0 to 30 microseconds (upper position).

Bin Power
Accepts power from the NIM Bin.

EXT BUSY
Accepts INHIBIT signal from a 2101 TRP preamp. Not used with detectors equipped with a 2001 or 2002 preamp.

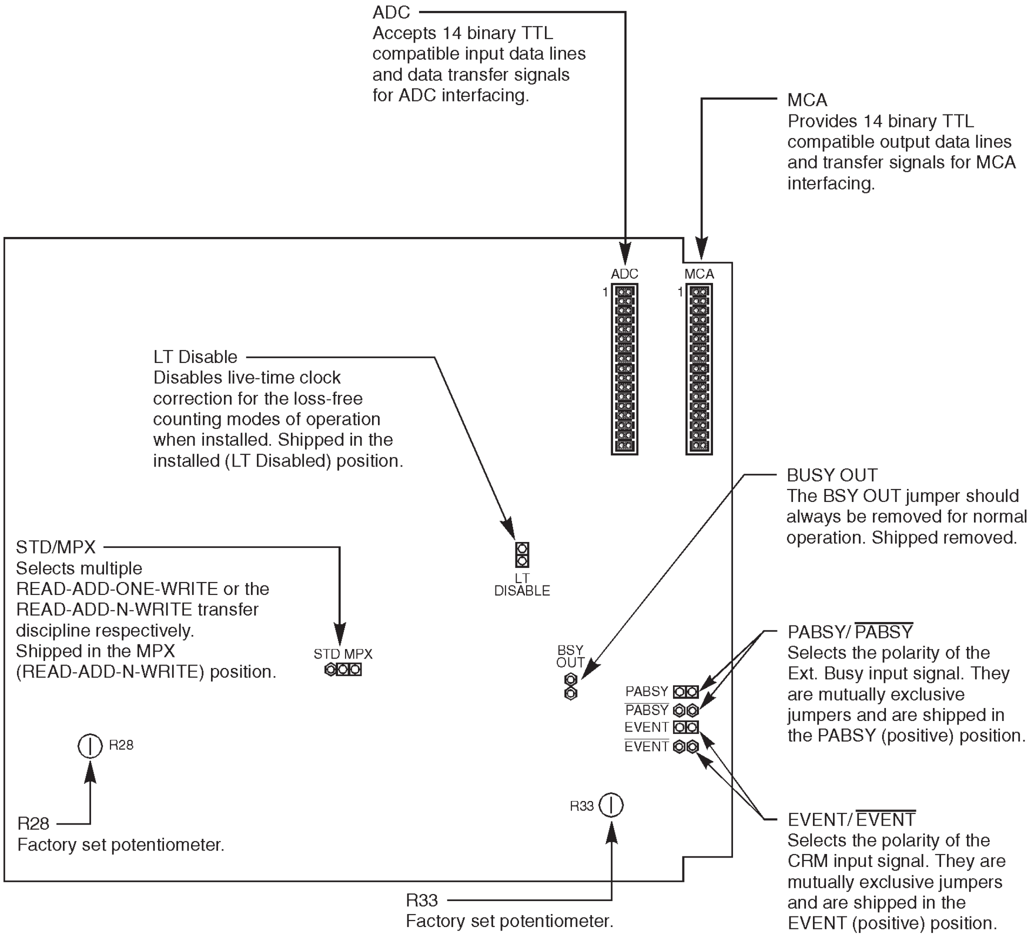
CRM
(Count Rate Monitor)
Accepts the ICR signal from the associated spectroscopy amplifier.

LTC/PUR
Provides the LTC/PUR interface for the ND 590 series of amplifiers. This connector is not used with the 9615 or 202X series of amplifiers.

Figure 2 Rear Panel Controls

Internal Controls

This is a brief description of the 599's internal jumpers. They should be set for your specific requirements before applying power to the module. For more detailed information, refer to Appendix A, Specifications.



ADC
Accepts 14 binary TTL compatible input data lines and data transfer signals for ADC interfacing.

MCA
Provides 14 binary TTL compatible output data lines and transfer signals for MCA interfacing.

LT Disable
Disables live-time clock correction for the loss-free counting modes of operation when installed. Shipped in the installed (LT Disabled) position.

BUSY OUT
The BSY OUT jumper should always be removed for normal operation. Shipped removed.

STD/MPX
Selects multiple READ-ADD-ONE-WRITE or the READ-ADD-N-WRITE transfer discipline respectively. Shipped in the MPX (READ-ADD-N-WRITE) position.

PABSY/$\overline{\text{PABSY}}$
Selects the polarity of the Ext. Busy input signal. They are mutually exclusive jumpers and are shipped in the PABSY (positive) position.

R28
Factory set potentiometer.

EVENT/$\overline{\text{EVENT}}$
Selects the polarity of the CRM input signal. They are mutually exclusive jumpers and are shipped in the EVENT (positive) position.

R33
Factory set potentiometer.

Figure 3 Internal Controls

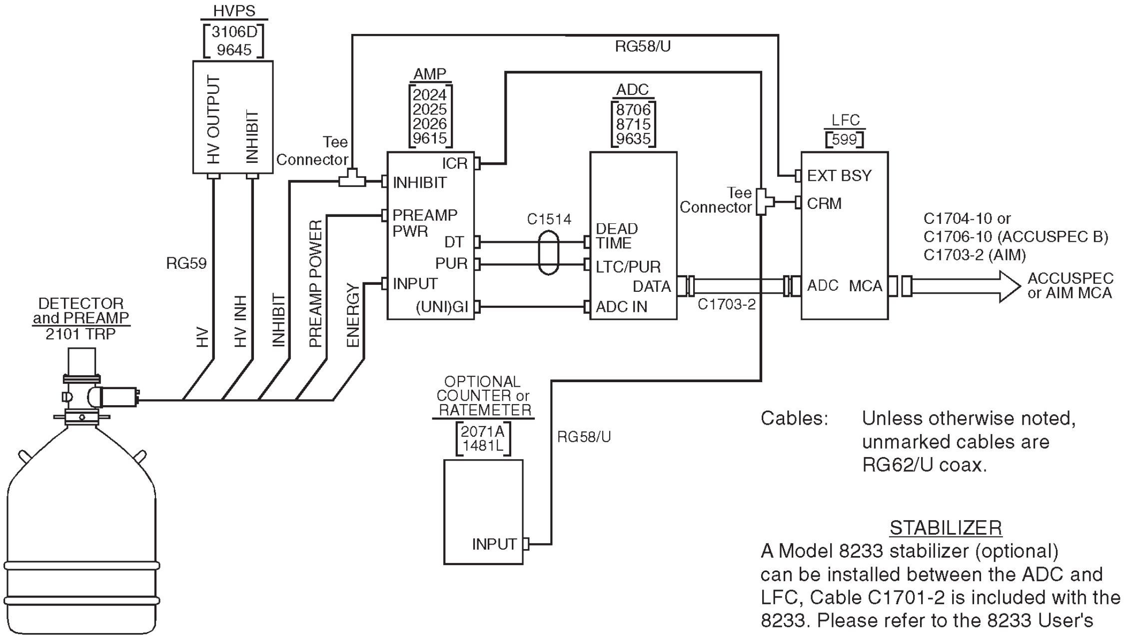
3. Operation

This section discusses the use of the 599’s controls and functions.

LFC System Configuration

The Model 599 LFC is configured and cabled as shown in Figure 4. The following Jumper plugs and settings in the associated units must be changed from their factory default to operate with the Model 599 LFC.

GENERAL SYSTEM SETUP



Cables: Unless otherwise noted, unmarked cables are RG62/U coax.

STABILIZER

A Model 8233 stabilizer (optional) can be installed between the ADC and LFC, Cable C1701-2 is included with the 8233. Please refer to the 8233 User's Manual for setup and operating instructions.

INHIBIT OUTPUT: For detectors equipped with a 2001 or 2002 preamp, the INHIBIT function is not used.

Figure 4 General System Setup

Table 1 Jumper Plugs and Settings in Associated Units

Model	Jumper Plug	Factory Default	For LFC Operation
2024*	J6	DT	BSY, PUR Enabled.
2025,2026	W6	DT	BSY, PUR Enabled.
9615			Change LTC mode to LFC.
Accuspec B	U25	LFC Closed	LFC Open (position 8) sets memory cycle to READ-ADD-N.
	Spec	8K	16K for use with dual LFC and 8K ADC memory size or 16K ADC.
Accuspec MC			Enabled LFC mode; performed through manual configuration in Reference Disk.
556 AIM			Set MCA Acquisition mode to LFC.

NOTE: Refer to the respective Operator's Manual for specific Setup/Operating instructions.

*On 2024s built after January 1, 1992. Older 2024s require modifications. Consult the factory for more information.

Front Panel

LFC Enable

This green lamp indicates that the 599 LFC Module is performing loss-free counting. This condition occurs whenever the 599 LFC is switched to the LFC, AUTO 1 or AUTO 2 mode, and the MCA acquisition is turned on.

Overflow

This red lamp indicates that an arithmetic overflow of the internal loss-free counting logic has occurred. The lamp can only indicate an overflow when the 599 LFC is in the LFC, AUTO 1, or AUTO 2 mode and the MCA acquisition is on. The OVERFLOW lamp will light when and if the overflow occurs. Once lit, the lamp remains on until the MCA acquisition is terminated. The OVERFLOW lamp is also used for calibration when the 599 LFC is switched to the CAL mode. A complete description of this function is provided in the Calibration section.

Mode Selection Switch

This 6-position rotary switch selects the 599 LFC mode of operation. A brief description of these modes follows. Refer to Table 2 for some of the characteristics and requirements for each mode.

OFF

Returns the system to normal operation as if the 599 LFC were not connected in the system. The OFF position allows the user to operate using standard MCA live-time correction (LTC) where the Amplifier/ADC Dead Time gates the MCA live time clock.

CAL

Selects a special non-data mode of operation, allowing the user to preset the PET Monostable to its proper setting. The OVERFLOW LED on the front panel indicates proper adjustment (for Gaussian shaping only) of the PET Monostable. It lights if the setting is too large and extinguishes if the setting is too small. The front panel heli-pot should be adjusted until the LED is partially lit. The ability to directly compare the mono and system inspect front panel test points to verify proper adjustments is also provided. (Refer to “Calibration” on page 13 for more detailed information.)

LT

Selects a precision live-time mode of operation. This live-time mode is different from the standard MCA live-time (operating in the OFF position) in that it uses the virtual pulse generator technique described in Dr. Westphal’s 1981 paper. The LT mode extends the collection time, and with the PET monostable properly adjusted, this mode provides a significant improvement in the system live-time accuracy, especially at high counting rates.

LFC

Selects the Westphal loss-free counting technique. Proper adjustment of the PET Monostable is required; however, once calibrated, this mode provides the most accurate loss-free counting. Live time correction is performed in real time without extending the collection time.

AUTO 1

Selects the first automatic loss-free counting mode. No adjustments are required for accurate loss-free counting. This mode computes the system losses the same way normal MCA live-time mode losses are computed. Correction is based on Amplifier/ADC Dead Time, but this Dead Time is not passed on to the MCA. It also may be desirable to operate in this mode if no fast discriminator output is available from the amplifier.

AUTO 2

Selects second automatic loss-free counting mode. No adjustments are required for accurate loss-free counting. This mode is based on counting pulses from the detector via the amplifier fast discriminator. For every input pulse counted, a corresponding event is stored in memory. The accuracy of this scheme is good at medium to high count rates.

Table 2 Mode Selection Switches and their Characteristics and Requirements

Mode	Type	Technique	LTC/PUR Input Signals	Calibration Required	Overflow Lamp
OFF:	Live-Time	LTC	AMP-INH*	No	
CAL:	Non-Data	Special	AMP-INH*, AMP BUSY, CRM		Calibration Indicator
LT:	Live-Time	Westphal VPG	AMP-INH*, AMP BUSY, CRM	Yes	
LFC:	Add-N	Westphal VPG	AMP-INH*, AMP BUSY, CRM	Yes	Math Overflow
AUTO1:	Add-N	Virtual LTC	AMP-INH*	No	Math Overflow
AUTO2:	Add-N	Harms	AMP-INH*, CRM	No	Math Overflow

* From some preamplifiers (TRP)

Pulse Evolution Time (PET) Monostable

This (10-turn) potentiometer adjusts the timing of the internal PET Monostable. The control adjustment range is nominally 0 to 10 microseconds.

A rear panel slide switch can be set to allow an adjustment range from 0 to 30 μs. In this case, the dial reading must be multiplied by three. The dial is designed to be reasonably accurate in representing the actual monostable timing; however, it is not intended to be used for calibration purposes. The recommended methods of calibrating the 599 LFC (see "Calibration" on page 13) should always be used, while the dial reading should only be used as a guideline.

Mono Inspect

This front panel test point is provided to allow direct oscilloscope monitoring of the PET Monostable. The monostable functions in only the CAL, LT, and LFC modes of operation. The quiescent state of the signal is approximately 0 V. The signal will switch to approximately +5 V for the duration of the monostable.

System Inspect

This front panel test point is provided to allow direct oscilloscope monitoring of the actual pulse evolution time of the system, and this signal functions in any of the six modes. The quiescent state of the signal is approximately 0 V. The signal will switch to approximately +5 V for the duration of the system pulse evolution time.

The definition of the system pulse evolution time is, the minimum time duration that the system can be NOT-BUSY and still theoretically accept an input event without that event being rejected. In practice, this is approximately the time duration of the amplifier fast discriminator triggering until the ADC peak detect time.

Rear Panel Controls and Connectors

The following paragraphs describe the function and purpose of the Rear Panel Controls and Connectors.

EXT BUSY

This BNC connector provides an input signal to the 599 LFC. Specifically, the EXT BUSY signal is designed to allow logical O-Ring of the system BUSY with the INHIBIT or BUSY signal from a transistor reset type of preamplifier. Internal PABSY jumpers allow acceptance of either positive true signals (standard) or 0 V true signals (optional). In general, however, the EXT BUSY signal may be used to allow logical of any system signal with the system BUSY. This signal is optional.

Logical High = 4 to 5 V
Logical Low = 0 to 1 V

CRM

This BNC connector provides an incoming count rate input signal to the 599 LFC. Specifically, the CRM (count rate monitor) is designed to accept the fast discriminator output signal (ICR) from the associated spectroscopy amplifier. Internal EVENT jumpers allow acceptance of either positive true signals (standard) or 0 V true signals (optional), and is required for proper operation of the 599 LFC.

Logical High = 4 to 5 V
Logical Low = 0 to 1 V

RANGE

This two-position slide switch selects the PET Monostable range. When the RANGE switch is in the lower position (selecting the lower range), the PET Monostable will have a range of 0 to 10 µs. The PET Monostable dial can be read directly in microseconds. When the RANGE switch is in the upper position (selecting the upper range), the pulse evolution time monostable will have a range of 0 to 30 µs and the PET Monostable dial must be multiplied by a factor of three.

LTC/STAB

This five-pin Molex connector provides the necessary input and output signals for connection to the amplifier pulse pileup rejection circuitry of the ND 590 series of amplifiers.

Internal Jumpers

LT Disable

The live-time disable (LT Disable) is shipped from the factory installed. As the name implies, the jumper plug, when installed, disables the live-time clock correction when the 599 LFC is switched into one of the three loss-free counting modes (LFC, AUTO1, or AUTO2). In these modes, the MCA live-time clock will run in step with the real-time clock indicating real-time data correction.

It may, however, be desirable to enable the live-time clock while doing loss-free counting. The ratio of real-time to live-time clocks then shows the average weighting factor N during the acquisition period. However, care must be taken *not* to operate the analyzer for a fixed live-time because data will then be corrected both by extended time and mathematical weighting. Also, results of various programs (Peak Search) can give erroneous results based on live-time. Remove jumper LT DISABLE if this option is desired. If the Dual LFC mode is used (see Appendix E), this jumper must be removed.

MPX vs. STD Transfer Discipline

The MPX and STD jumper plugs select the type of data transfer discipline provided for the weighting factor N. The 599 LFC is shipped with the MPX transfer discipline enabled. This is the transfer mode used in Accuspec or AIM MCAs.

It provides for a multiplexed transfer of both ADC data and weighting factor N over the same standard 34-pin ADC interface cable. In this mode, two words are transferred to the MCA for each event. Each provides its own READY signal and each requires its own CLADC and ATR signal in response. The first word is the N value accompanied by the ADC INHIBIT signal. The second word is the data itself that may or may not be accompanied by the INHIBIT signal. When using the 599 LFC with an older model MCA (one not equipped with the READ-ADD-N-WRITE memory cycle feature), it will be necessary to change the 599 LFC Transfer Discipline from MPX to STD.

The STD configuration does not require the MCA to perform READ-ADD-N-WRITE memory cycles. Instead, the 599 LFC causes the MCA to perform multiple READ-ADD-ONE-WRITE memory cycles. For example, if N=3 for a given event, then the 599 LFC will provide three ADC transfers to the MCA causing it to do three READ-ADD-ONE-WRITE memory cycles to the specified channel.

This latter situation provides the same benefits and accuracy of the updated MCA except for count rate. Essentially, the maximum detector input count rate is limited to the maximum input rate of the MCA. Typically, this is around 100 kHz. However, some margin must be provided for statistical variations in the value of N; 50 kHz is a more realistic limit. The 599 LFC OVERFLOW lamp can be used to determine when the maximum input rate has been exceeded.

To invoke this option, remove jumper MPX and install jumper STD. If the Model 703072 Dual LFC option is installed, it must be jumpered as well. Refer to Appendix E for details on operating the Dual LFC.

EVENT vs. $\overline{\text{EVENT}}$

The EVENT/$\overline{\text{EVENT}}$ option provides the 599 LFC with the ability to accept either a positive true or negative true signal, respectively, on the CRM signal BNC. The EVENT option provides a signal termination of 330 Ohms to ground. The $\overline{\text{EVENT}}$ option provides a signal termination of 2200 Ohms to +5 Volts.

PABSY/$\overline{\text{PABSY}}$

The PABSY /$\overline{\text{PABSY}}$ option provides the 599 LFC with the ability to accept either a positive true or negative true signal, respectively, on the EXT BUSY signal BNC. The PABSY option provides a signal termination of 330 Ohms to ground. The $\overline{\text{PABSY}}$ option provides a signal termination of 2200 Ohms to +5 Volts.

BUSY OUT

The BUSY OUT option jumper should always be removed for normal operation. In the event the user should want to use the standard live-time correction built into the Canberra 202X amplifier, this jumper must be installed. The 599 LFC must then be operated in the OFF mode.

Calibration

Calibration of the virtual pulse generator (VPG) is essential for operation in the Westphal LT or LFC mode. The more accurate the system is calibrated, the more accurate are the results. The calibration consists of simply adjusting the PET Monostable to its proper setting. Once adjusted, the PET Monostable will not require readjustment unless any of the following system changes are made:

- Amplifier shaping time is changed.
- Amplifier is physically replaced.
- ADC unit is physically replaced.
- ADC conversion gain is altered. (Models 8701 or 8706 ADCs only)
- Detector is replaced.
- Preamp is replaced.
- Pole/Zero is adjusted.

In general, should any system component be altered or replaced, checking of the PET Monostable calibration is recommended. It should be the last system adjustment made.

CAL Mode (For use with Gaussian Shaping Amplifiers)

To assist the user in performing the PET Monostable calibration, the 599 LFC has been equipped with a special calibration mode (CAL). In this mode, all data acquisition is inhibited. The object of the calibration is to adjust the PET Monostable to be exactly equal to the system pulse evolution time.

Signals are provided on the 599 LFC front panel that represent both the PET Monostable time and the derived system PET Monostable evolution time. Signal MONO INSPECT is a positive pulse representing the PET Monostable. Signal SYSTEM INSPECT is a positive pulse representing the true pulse evolution time of the system. In CAL mode only, the PET Monostable is triggered at the same time that the pulse evolution time begins. This is not normally the situation; this allows the user to directly compare the waveforms on the two test points with an oscilloscope, while the 599 LFC is operating in the CAL mode. The PET dial can then be adjusted until the two signals have identical timing.

The CAL mode also allows the 599 LFC Front Panel Overflow lamp to be used as a calibration tool. With a low-to-moderate system input count rate, the overflow light will provide the following information:

OVERFLOW FULLY ON:	Pet Monostable Time Too Long
OVERFLOW OFF:	Pet Monostable Time Too Short

To initially calibrate the PET Monostable: The 599 LFC must be in the CAL mode; the MCA must have acquisition turned on for the ADC connected to the 599 LFC; and a low-to-moderate input count rate must be applied via a sample source to the detector. Record the PET dial setting for the LED FULLY ON and OFF conditions. The proper setting is acquired by adjusting the dial mid-way between these readings. However, it should be noted that these calibration techniques only provide a *close* system calibration that gives accurate (but not ideal) results. The ultimate technique for calibrating the PET Monostable is described in the following section.

Two-Source Calibration

Before attempting the two-source Calibration, the 599 LFC should be calibrated using the previously described techniques. This provides *near* calibration and makes the two-Source Calibration Technique easier.

A reference gamma source should be positioned near the detector (such as ^{60}Co) to provide a low integral count rate (1000 to 10K events/sec.):

- This source should be fixed so as not to vary during the calibration procedure.
- The LT or LFC mode should be selected.
- Acquire a spectrum for a fixed time long enough to provide good statistics in the reference peak.
- Apply a second active source (such as ^{137}Cs) to the detector to provide an integral count rate of 100 - 200K events per second.
- *Do not* disturb the reference source. Also, when placing the second source near the detector care should be taken not to block the path of the gamma rays from the reference source. Even high energy gammas like ^{60}Co will be absorbed to some degree by an obstruction in the path. This can lead to erroneous measurements.
- Acquire a spectrum for the identical fixed live-time.
- Compare the reference peak areas for low and high count rates. The upper ^{60}Co peak at 1332.5 keV should not be used because of interference from the sum

peak of ^{137}Cs (2 x 661.2 = 1322.4). This assumes a high resolution detector (e.g. Germanium); an NaI detector would probably be unable to clearly separate the two ^{60}Co peaks.

If at high count rates the peak area has decreased, increase the PET Monostable setting (a small amount) and run both tests again. If at high count rates the peak area has increased, decrease the PET Monostable setting (a small amount) and run both tests again. If gross differences appear between low and high count rates, recheck all connections between the 599 LFC and the amplifier.

PET Monostable Range Switch

The 599 LFC is equipped with a rear panel RANGE switch. This switch provides two ranges of PET Monostable adjustment: High Range (switch up) provides an adjustment range of 0 to 30 µs; Low Range (switch down) provides an adjustment range of 0 to 10 µs.

The Low Range is always preferred because it provides better PET Monostable stability, better resolution, and a more convenient dial reading. However, if the 599 LFC is used with long pulse evolution times, it may be necessary to switch the RANGE switch to the High position. The dial reading will be multiplied by three for the High Range.

Note: The PET Monostable dial (although quite accurate in representing the actual PET Monostable timing) is not designed to be an absolute gauge, only a relative indication of the monostable timing. *Do not* use the dial setting as a calibration tool.

2024/GI Calibration

For high count rate applications, the Models 8715 or 9635 ADC and 2024 Fast Spectroscopy Amp with Gated Integrator (GI) function can be used to optimize system throughput.

Gated Integrator shaping minimizes the effects of ballistic deficit that is normally encountered with fast shaping times and Germanium detectors. Shorter shaping times (0.25 ms, 0.5 µs) can be used for increased throughput with minimal spectral broadening.

Refer to the 2024 User's Manual for specific details regarding its operations and setup.

The 2024 Amplifier GI signal processing is slightly different and the PET monostable must be manually set using an oscilloscope, as described below and shown in Figure 5.

PET Monostable Setup for 2024

1. Using a scope probe, connect channel 1 of the oscilloscope to the Peak Detect Insp test point on the 8706/8715/9635 ADC.

2. Note the time duration of the ADC Peak Detect Inspec signal.

3. Set the Mode Switch on the Model 599 LFC to CAL. Monitor the Mono Inspect test point using channel 2 of the oscilloscope. Adjust the Pulse Evolution Monostable until the PET Monostable pulse duration matches the Peak Detect Inspect pulse duration as noted in step 2.

4. Return the LFC mode switch to the LT or LFC mode as required.

5. To optimize the PET monostable, perform the steps outlined in the previous section, Two-Source Calibration.

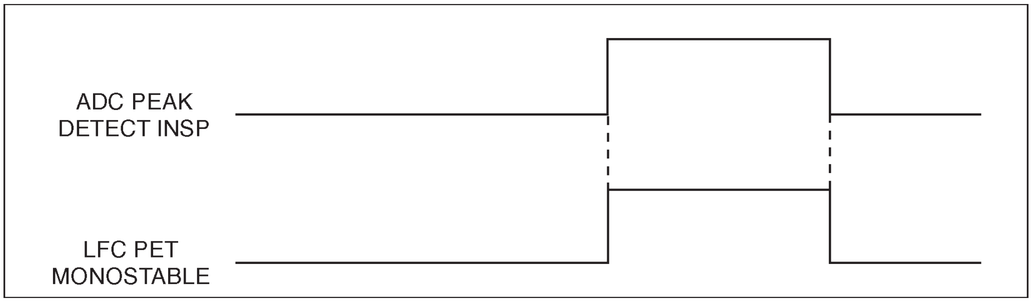


Figure 5 PET Monostable

References

Harms, J., “Automatic Dead-Time Correction for Multichannel Pulse-Height Analyzers at Variable Counting Rates”. Nuclear Instruments and Methods, Vol. 53 (1967), 192–196.

Westphal, G. P., “Real-Time Correction of Counting Losses in Nuclear Pulse Spectroscopy”. Journal of Radioanalytic Chemistry, Vol. 70, Nos. 1-2 (1982), 387–410.

A. Specifications

Inputs

ADC - The 14 binary TTL-compatible input data lines and the data transfer command lines for the ADC interface; 34-pin rear panel ribbon cable connector for the C1703-2 ADC Mating Cable.

EXT BUSY - Preamplifier Inhibit; allows the CMOS compatible output signal from a reset preamplifier to be logically ORed with the ADC BUSY signal; either positive or negative true signal polarity is selectable via internal jumpers. Factory setting is positive true, rear panel BNC connector.

CRM - Count rate monitor; accepts a CMOS compatible, 50 ns minimum width, fast discriminator or ICR (incoming count rate) signal from an associated amplifier; either positive or negative true signal polarity is selectable via internal jumpers, factory setting is positive true; rear panel BNC connector.

Outputs

MCA - The 14 binary TTL-compatible output data lines and the data transfer command lines for the MCA interface; 34-pin rear panel ribbon cable connector.

LTC/PUR - Rear panel 5-Pin Molex Connector.

BUSY OUT (Pin 1) - Output signal at +4 V (± 1 V) when the ADC is free to accept events and at 0 V (0 V, +0.5 V) when the ADC is busy processing an event; factory jumper setting is BUSY OUT disabled.

BLOCK (Pin 2) - Positive true CMOS level input which is accepted during the time the ADC's linear gate is open to set the inhibit flag and reject the event. BLOCK signal requirements: +3.6 V to +5V to block, 0 V (0 V, +0.5 V) to allow storage, Zin = 300 Ω.

GROUND - Pin 3.

BUSY IN +/– (Pin 4/5) - Positive (+)/ground level (–) inputs which are logically ORed with internal ADC busy status to form system busy; BUSY IN + signal requirements: +3.6 to +5V when busy, 0 V (0 to +0.5V) when not busy, Zin = 2.2 kΩ.

MONO INSPECT - Allows direct oscilloscope monitoring of the Pulse Evolution Time (PET), which functions only in the CAL, LT and LFC modes; quiescent state 0 V, switches to +5 V for the duration of the PET; front panel test point.

SYSTEM INSPECT - Allows direct oscilloscope monitoring of the system Pulse Evolution Time; functions in all modes; quiescent state 0 V, switches to +5 V for the duration of the system Pulse Evolution Time; front panel test point. The definition of the system Pulse Evolution Time is the minimum time the system can be not busy and still theoretically accept an input event without being rejected.

Indicators

LFC ENABLE - Green LED indicates the LFC module is performing loss free counting (LFC, AUTO 1 or AUTO 2 mode is selected and MCA acquisition is turned on).

OVERFLOW - Red LED indicates an arithmetic overflow of the internal loss free counting logic has occurred; indication provided only when LFC, AUTO 1 or AUTO 2 mode is selected and MCA acquisition is turned on. The OVERFLOW LED lights when and if an overflow occurs. Once lit, it remains on until MCA acquisition is terminated. This LED can also be used for calibration when the CAL mode is selected.

Front Panel Controls

MODE SWITCH - Selects the 599’s operating mode; six-position rotary switch.

OFF - Turns off the LFC circuitry, allowing operation using standard MCA live time correction.

CAL - Selects a special non-data mode of operation, allowing the user to preset the Pulse Evolution Time (PET) to its proper setting. The OVERFLOW LED on the front panel is a user aid for proper setting of the PET; operational in the CAL mode.

LT - Selects the precision live time mode of operation. This live time mode is different from the standard MCA live time (operating in the OFF position) in that it uses the Westphal Virtual Pulse Generator (VPG) technique to generate a precision live time which extends the measurement duration to correct for counting losses. Proper adjustment of the PET is required.

LFC - Selects the Westphal Loss-Free Counting technique. Proper adjustment of the PET is required. Dynamically corrects for counting losses in real time by performing an “Add-N” or “Read-Add-N” MCA transfer.

AUTO 1 - Selects one of the automatic loss-free counting modes. No adjustments are required for accurate loss-free counting. This mode computes the system losses the same way normal MCA live time mode losses are computed. Switching from OFF to AUTO 1 provides a direct comparison between live time correction and loss-free counting. It also may be desirable to operate in this mode if no fast discriminator output is available from the amplifier. This method is not as accurate as the LFC mode.

AUTO 2 - Selects the second automatic loss-free counting mode. No adjustments are required for accurate loss-free counting. This mode is based on counting pulses from the detector via the amplifier fast discriminator. For every input pulse counted, a corresponding event is stored in memory. The accuracy of this scheme is good at medium to high count rates.

PULSE EVOLUTION MONOSTABLE - Adjusts the timing of the internal Pulse Evolution Time (PET) monostable; normally calibrated from 0 to 10 µs; rear panel RANGE switch (two-position slide switch) allows selecting an adjustment range from 0 to 30 µs (multiplying dial reading by 3); 10-turn locking dial precision potentiometer.

COMPATIBILITY - Connects directly to AccuSpec/B and AccuSpec/MC MCAs, 556 AIM, Canberra 87xx and 963x ADCs, and ND58x ADCs. Consult factory for compatibility with other MCAs and ADCs.

Performance

Typical Accuracy

Typical* peak-area accuracy over varying spectral count rates:

Mode	0-100 kHz	0-200 kHz
LFC	±2%	±5%
LT	±2%	±5%
AUTO 1	±10%	—
AUTO 2	±10%	—

*1.0 µs Gaussian shaping and 5 µs Fixed Conversion Time ADC giving 95% losses at 200 kHz.

VIRTUAL PULSE GENERATOR - Frequency 5 MHz; absolute accuracy ±0.01%; temperature coefficient ±0.01% over operating temperature range.

PULSE EVOLUTION TIME MONOSTABLE - HI Range 0-30 µs; LO Range 0-10 µs; stability (above 2 µs) ±2% over time and temperature.

ADD-N WEIGHTING FACTOR RANGE - 1 to 255.

Environmental

OPERATING TEMPERATURE RANGE - 0 to 40 °C.

HUMIDITY - Up to 95%, non-condensing.

Power Requirements

+12 V dc – 400 mA –12 V dc – 10 mA

Accessories

Model C1703-2 - Model 599 to ADC mating ribbon cable, 34-pin to 34-pin; 61 cm (2 ft); included with the 599.

Options

Model 703072 Dual LFC Mode.

Physical

SIZE - Standard single width NIM module 3.43 X 22.12 cm (1.35 X 8.71 in) per DOE/ER-0457T.

NET WEIGHT - 0.9 kg (1.9 lb).

SHIPPING WEIGHT - 1.8 kg (4.0 lb).

B. The Loss-Free Counting Technique

Live-time Correction (LTC) is commonly used to compensate for the time or pulses lost when a spectroscopy system is unavailable (busy) processing an accepted pulse. The quantitative measurement of radioactive decay requires that the time the system was available to accept a pulse (the live time) be known and most measurements are performed, for statistical reasons, to a specific live time. LTC corrects for system losses by extending the duration of the counting time. At extreme count rates, even with fast amplifiers and ADCs, the extension of the counting period required for LTC measurements may make the measurement last so long as to make the data worthless. LTC also does not respond well to real-time situations or to the measurement of samples with short half-lives. Such situations include neutron activation analysis, process monitoring, and effluent and stack monitoring. Loss-Free Counting (LFC), a statistical method of correcting for losses in spectroscopy system electronics, was developed to address these situations. It is also useful for other counting situations since it provides counting for a fixed real (clock) time.

This Application Note discusses the principles of Loss-Free Counting, with an emphasis on the Virtual Pulse Generator Method that is incorporated in the 599 Loss-Free Counting Module. Some tests of this technique in nuclear spectroscopy are also presented. In this note LTC refers to classic Live-time correction, not the precision LT operating position of the 599 LFC.

Loss-Free Counting Methods

Several methods of Loss-Free Counting (LFC) have been described in the literature. All methods provide for the operation of the Pulse Height Analyzer in a read-add n-write mode, where n is a weighting factor that is derived in some manner from the number of pulses lost in the counting system electronics while they are busy. The methods differ in how the weighting factor is derived and in their ability to respond to rapid changes in the count rate.

The Harms (1) method uses a scaler to count the number of preamplifier pulses that are presented to the analog electronics and rejected while the electronics are busy. The weighting factor calculated from the scaler contents is used when the following accepted event is processed. Adding n to the following event, not the current event, avoids skewing the spectral data. The Harms method does not take pulse pileup in the spectroscopy amplifier into account, and its use has been limited as a result.

An almost ideal situation is given by the pulser method, but it too has disadvantages. The pulser method uses a train of test pulses that are introduced to the preamplifier. Those pulses are used to determine the losses within a spectroscopy system by comparing the number of the test pulses accepted to the total of those presented, and the weighting factor for loss correction is the ratio of total pulses to accepted ones. The pulser method does not have any of the drawbacks of the Harms or LTC methods, but it does require a highly reproducible pulse with an amplitude that will not interfere with any photopeak of interest in the sample. The pulser method can operate in real-time, but it is primarily useful for the measurement of long-lived isotopes where the weighting factor does not change radically over time. For applications such as process control, where a plug of material can quickly pass by the measurement station, the pulser would have to have a kilohertz frequency for the spectroscopy system to properly respond. This would interfere with the spectroscopic measurement due to the large number of pulser events that would have to be processed.

Virtual Pulse Generator

1981 Westphal presented the Virtual Pulse Generator (VPG) technique of loss-free counting (4). The VPG technique has been incorporated in the LT and LTC modes of the 599 Loss-Free Counting Module. The intent of the technique is to provide a real-time correction method that has the advantages of the pulser method; but one that does not require the pulser itself. By testing the status of the system frequently, an analogous situation to the pulser method is derived by continuously inspecting both the baseline of the shaping amplifier and the MCA System Busy signal. Pulse Evolution Time (PET) is defined as the time from the point that a theoretical pulse rises above baseline noise to its peak. For a successful test, the VPG technique requires that the amplifier baseline remain steady for one PET and that the MCA is not busy at the end of the PET. This simulates the case where the pulser injects pulses, but is not burdened with the overhead associated with the processing of pulser data. The PET test is done using a 5 MHz pulser rate. The weighting factor, n, to be applied to the events processed during the next inspection period, is calculated approximately every 10 μsec from the ratio of total trials to successful trials. Because the pulser is not required trials may overlap for better precision on the weighting factor.

To properly account for the testing cycle, one Pulse Evolution Time is added to the System Busy signal. This completes the simulation of the case where the pulser injects a pulse. Figure 6 illustrates the concept of the VPG technique. It shows the extension of System Busy by one PET.

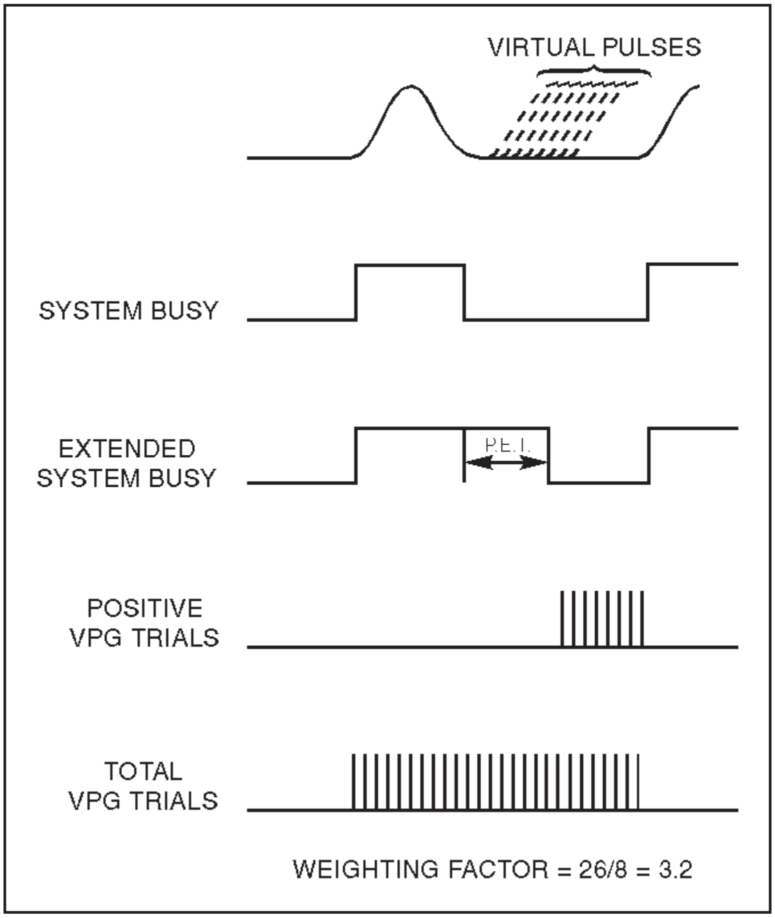


Figure 6 Virtual Pulse Generator Concept

Because the VPG technique corrects for total losses on a real-time basis, there is no need to extend the counting period as is done in LTC. All measurements are performed for a preset real (clock) time. However, the statistics of the data change slightly. The statistics are a direct function of both the number of ADC conversions performed and the square root of the average weighting factor being applied. The MCA is performing an add-n memory cycle instead of the normal add-1 cycle, so the statistics of the measurement are no longer directly proportional to the number of counts in a given channel. If a spectrum is collected using an average weighting factor of four (75% of the pulses presented are lost), the statistical error of the measurement calculated by normal methods must be doubled to account for the fact that only one out of four pulses is real, the other three being added by the VPG technique. In general, the statistical errors associated with the VPG technique will be higher than those derived from LTC methods, but the measurement's shorter duration will more than compensate for the increased error limits. Table 3 illustrates some counting times for both LTC and VPG techniques and their associated errors for a well defined peak.

Table 3. Elapsed Counting Times and % Statistical Error Limits for LTC and VPG Techniques.*

Input Count Rate	Elapsed Time LTC	% Statistical Error	Elapsed Time VPG	% Statistical Error**
14K	5:59	0.41	5:00	0.46
55K	9:11	0.40	5:00	0.63
72K	10.33	0.42	5:00	0.86
110K	14:30	0.42	5:00	0.98
130K	16:14	0.43	5:00	1.22
160K	19:30	0.45	5:00	1.61

**For 1332 keV Co-60 peak, nominal peak area 59.8K counts. The % error is defined as N+2B/N where N = net area and B = background area.

Advantages of the Virtual Pulse Generator Method

The VPG technique has several advantages, including real-time correction, no extension of the counting time and higher count rate performance. First, all data are corrected in real-time, that allows the spectroscopy system to properly respond to a wide range of count rates. Second, with all counting done to clock (real) time, the major disadvantage of LTC where the counting period may be extended to a very long time is also avoided. VPG measurements are of a fixed duration. Third, the VPG technique has been proven to provide statistically accurate results at count rates up to 700 kHz (4).

Some Tests of Loss-Free Counting

Count Rate Performance Test

The first test was designed to show the performance of a system in determining a small amount of activity in the presence of a large activity of another, second isotope. For this test, a low activity ^{60}Co source was used in a fixed geometry with a high activity ^{137}Cs source placed at varying distances from the detector to generate a variable counting rate. Count rates up to 200 kHz were employed. Figure 7 illustrates the percent busy value when LTC techniques are used. Also shown is the average weighting factor calculated for the VPG technique. At 100 kHz, the system is busy approximately 75 percent of the time resulting in the counting period being extended by a factor of three. The limiting factor in the electronics used is the spectroscopy amplifier's pulse shaping time. Faster amplifiers such as the Gated Integrator will alter the value of the curve on the vertical axis, but not the curve's form. Note that at 100 kHz, the average weighting factor is approximately five and at 200 kHz the weighting factor is 25. Weighting factors up to 255 are allowed, which is beyond the limits of most spectroscopy experiments.

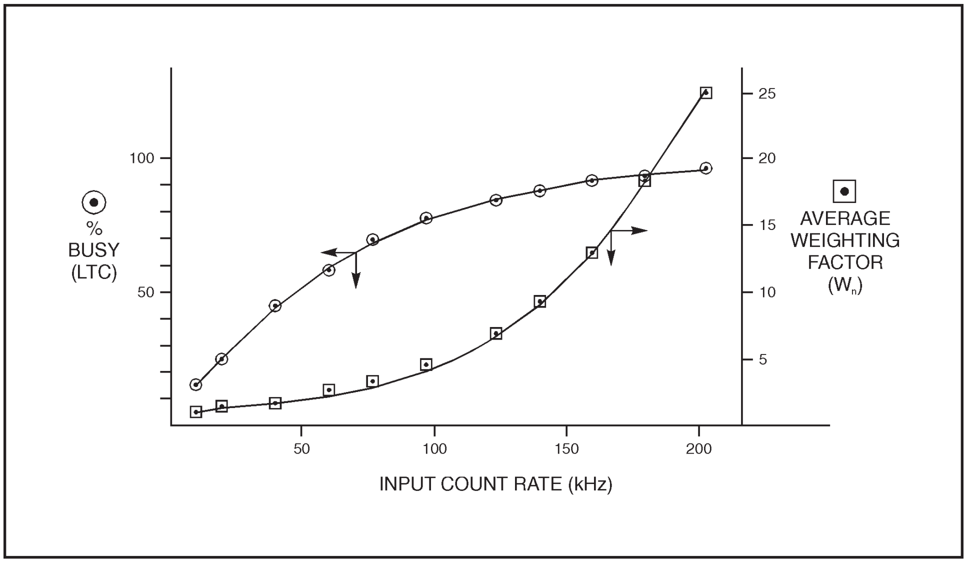


Figure 7 System Busy (Percent) for LTC Method and VPG Average Weighting Factor Versus Count Rate.

Figure 8 shows the calculated peak areas for the low-activity ^{60}Co photopeaks as a function of total count rate. The peak areas do not deviate by more than 5 percent over a 200 kHz range and Westphal's initial work (4) has shown this to be true up to 700 kHz.

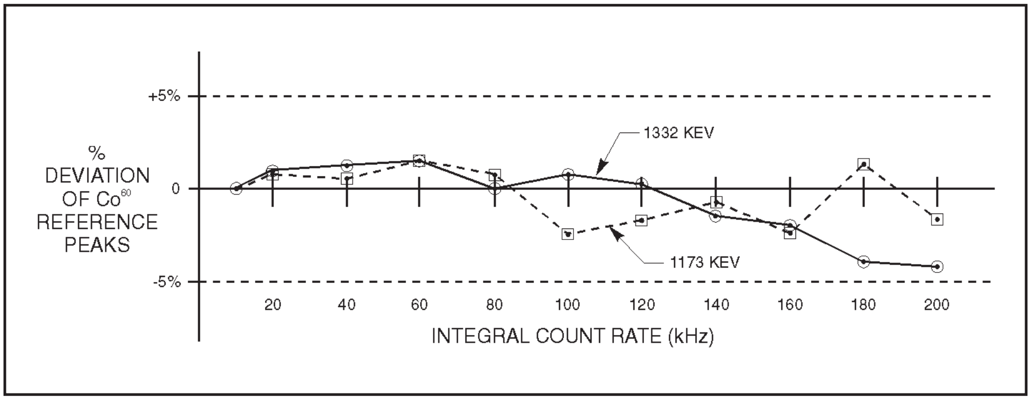


Figure 8 Percent Deviation from Reference for ^{60}Co Photopeaks using VPG as a Function of Total Count Rate Presented to the Detector

Table 4 illustrates the peak integral results for the low activity ^{60}Co photopeaks at 1173 and 1332 keV, the data taken at a 20 kHz rate. The results are in agreement within statistical error. For long-lived isotopes, the VPG technique yields correct results, within statistical error, over a large-count rate range while counting to a fixed real (clock) time.

Table 4. Comparison of LTC and VPG Peak Integral Results for ^{60}Co Photopeaks (LTC = 30% busy)

Peak(keV)	VPG	LTC	% Deviation
1173	1471102	1511364	-2.7
1332	1137790	1137342	0.04

Real-Time Performance

If the sample being analyzed has a short decay time relative to the counting time or if a plug of material were to pass quickly by a measuring station in a timeframe that is short relative to the counting time, the areas calculated for the associated peaks may be in error if LTC techniques are used. The activity associated with the plug is transient, and LTC will extend the measurement real time, but the peak areas for the transient material will be incorrect, particularly at high counting rates. VPG offers a way to dynamically correct for the fluctuating count rate. These types of situations are encountered in process control, stack monitoring, or nuclear medicine.

To simulate this real-time situation, a low-activity ^{60}Co source having an integral count rate of 2,500 counts per second was counted for ten minutes. For 20 seconds of real time of the experiment, a ^{137}Cs source having 64,000 counts per second was exposed to the detector. As shown in Table 5 where LTC techniques are used, the area of the 661 keV ^{137}Cs peak is understated by a factor of >3 (greater than 3), so any attempt to quantitatively measure the amount of ^{137}Cs is doomed to failure. Using the VPG technique, the peak area is correct, within statistical error. To calculate the activity that the detector was exposed to, a record of the weighting factor or system busy signal versus time must be known, which is a small price to pay for correct results. This could be done by a second acquisition interface, recording events processed per second in multichannel scaling mode.

Table 5 Peak Integral Results for ^{137}Cs and ^{60}Co peaks under dynamic count rate conditions (ten minute counting time, ^{137}Cs used for 20 seconds to increase the count rate).

Isotope Peak (***)	Peak Area (LTC)	Peak Area (VPG)
^{137}Cs	68,165*	230,318
^{60}Co		
(1173 keV)	83,111	82,983
(1332 keV)	72,461	71,995

*^{137}Cs peak area, using 20 second live counting time is 231,067. This was for approximately 94 seconds of real time.

For real-time measurements, the VPG technique is the only method that will generate correct results with short counting times and varying input count rates.

Live Timing Accuracy

The VPG technique, if operated as a Live-Time Corrector, offers the possibility of precision counting. If the extended System Busy signal is used to gate the live-time clock, the elapsed live-time (and the counting period itself) is controlled by the dynamically calculated probability that the MCA is available to process a pulse. Figure 9 illustrates the count rate behavior of the low-activity ^{60}Co peaks as a function of count rate. The error becomes large at high counting rates due to baseline shift in the amplifier, preamplifier saturation, and pile-up rejection.

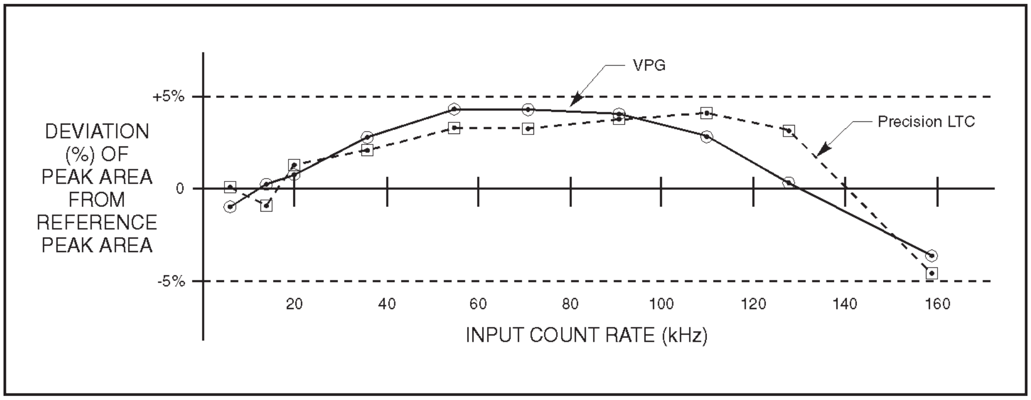


Figure 9 Comparison of Percent Deviation from Reference Value for ^{60}Co Photopeaks using VPG and Precision LTC Methods.

Conclusions

The 599 Loss-Free Counting Module, incorporating Virtual Pulse Generation techniques provides a method of statistically correcting for losses encountered in a spectroscopy system. The VPG technology allows rapid response to fluctuating count rates and provides results that are accurate within statistical error. All measurements being conducted to real (clock) time, instead of live-time, means that real-time data can be handled better and higher count rate performance can be achieved.

References

1. Harms, J. P., Nuclear Instr. Methods, *53* 192 (1967)

2. Westphal, G. P., Nuclear Instr. Methods, *146* 605 (1977)

3. Westphal, G. P., Nuclear Instr. Methods, *163* 189 (1979)

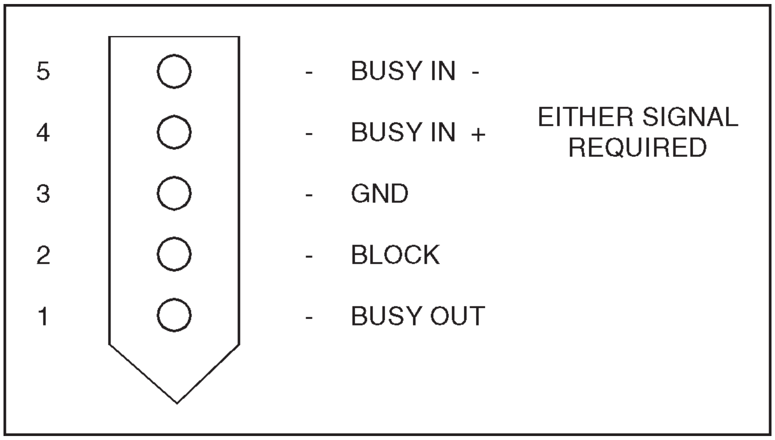
4. Westphal, G. P., Radioanalytical Chem. *70* 387 (1982), Austrian Patent 368291. U S. Patent Applied For.

C. Rear Panel Connectors

This section lists the details of the 599 LFC rear panel connectors.

LTC/PUR Connector

This 5-pin connector provides the LTC/PUR interface for the ND 590 series of amplifiers. This connector is not used with the 9615 or 202X series of amplifiers.



BUSY IN -	Input for Amplifier Busy Signal (0 Volt True) Logical 0 = +3.6 to +5 Volts Logical 1 = -0.5 to +0.5 Volt Impedance = 2200 Ohms Connected to +5 Volts
BUSY IN +	Input for Amplifier Busy Signal (Positive True) Logical 0 = -0.5 to +0.5 Volt Logical 1 = + 3.6 to +5 Volts Impedance = 330 Ohms
GND	Ground Return
BLOCK	Input for Amplifier Inhibit Signal Logical 0 = -0.5 to +0.5 Volt Logical 1 = +3.6 to +5 Volts Impedance = 330 Ohms
BUSY OUT	Logical 0 = +4.2 to +5 Volts @ -4.0 mA Max Logical 1 = 0 to +.5 Volts @ +4.0 mA Max

ADC Connector

Table 6 lists the signal name, the associated pin locations, and provides a brief functional description of the input/output signals for the 34-pin male I/O connector (labeled ADC) located on the printed circuit board of the 599 LFC Module.

Table 6. 34-pin Male I/O Connector Signal Description[1]

Signal	34-pin Desig.	Description
ADC00*	14	ADC Address Lines
ADC01*	16	
ADC02*	18	Input lines ADC00* through ADC07* are tri-state TTL devices. The tri-state bus drivers are enabled by the signal ATRX* (ENDATA*)
ADC03*	20	
ADC04*	22	Address bits: +5V = 0 0V = 1
ADC05*	24	
ADC06*	26	Off Output Impedance: Open circuit On Output Current: Up to 24 mA per line.
ADC07*	15	
ADC08*	17	Input lines ADC08* through ADC13X* are not modified by the 599. They pass through to the MCA connector (these signals are modified when the 703072 DSL option board is installed).
ADC09*	19	
ADC10*	21	
ADC11*	23	
ADC12*	25	
ADC13*	13	
ADC13X*	34	

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[1] The pin numbers shown are the wire numbers.

CLADCX* (ACEPT*)	2	Clear ADC Output. The steady state condition of signal CLADC* should be +5V. The ADC interface logic resets when signal CLADC* goes from +5 to 0V.
ATRX* (ENDATA*)	4	ADC Transfer Output. The steady state condition of signal ATRX* is +5V. Data transfer occurs when signal ATR* goes from +5 to 0V.
ADCB* (CDT*)	6	ADC Busy Input (Live Time) ADCB* represents the time the ADC cannot validly accept input pulses; the linear gate is closed. When not in ACQUIRE mode, ADCB* resides at +5V. (ADCB* is intended to be used for live-time control.)
ACQ* (ENC*)	8	Acquire Output Signal ACQ* is at 0V to enable the ADC or +5V to disable the ADC.
READY*	10	Ready Input. The steady state condition of signal READY* is +5V. Upon completion of a conversion, signal READY* goes to 0V to signal that data are ready to be transferred.
INH* (INV*)	12	Inhibit Input. Signal INH* is at +5V when information is acceptable and at 0V when information is to be rejected. Signal INH* is active only in the ADC’s NON OVERLAP mode.
GND	1,3,5, 7,9,11	Logic Signal Common
BCB*	33	Buffer Converter Busy Input. The steady state condition of signal CB* is +5V. Signal BCB* is at +5V when the ADC is not busy, and at 0V when it is busy. Passed through to the MCA.
N.A.	27,28	Reserved.
Unused	29,30,31,32	Pass through to MCA connector unmodified.

MCA Connector

Table 7 lists the signal name, the associated pin locations, and provides a brief functional description of the input/output signals for the 34-pin Male I/O Connector (labeled MCA) located on the printed circuit board of the 599 LFC Module.

Table 7. 34-pin Male I/O Connector Signal Description[2]

Signal	34-PinDesign*	Description
ADC00*	14	Buffer ADC Outputs. Output lines ADC00* through ADC07* are tri-state TTL devices. The tri-state bus drivers are enabled by the signal ATRX*.
ADC01*	16	
ADC02*	18	
ADC03*	20	
ADC04*	22	
ADC05*	24	Address bits: +5V = 0; 0 V = 1
ADC06*	26	Off Output Impedance: Open circuit. On Output Current: Up to 24 mA per line.
ADC07*	15	
ADC08*	17	Output lines ADC08* through ADC13* are not modified by the 599. They pass through from the ADC connector (these signals are modified when the 703072 DSL option board is installed.
ADC09*	19	
ADC10*	21	
ADC11*	23	
ADC12*	25	
ADC13*	13	
ADC13X*	34	

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[2] The pin numbers shown are wire numbers.

CLADC* (ACEPT*)	2	Clear ADC Input. The steady state condition of signal CLADC* should be +5V. The ADC interface logic resets when signal CLADC* goes from +5 to 0V.
ATRX* (ENDATA*)	4	ADC Transfer Input. The steady state condition of signal ATRX* should be +5V. Data transfer occurs when signal ATRX* goes from +5 to 0V.
ADCBX* (CDT*)	6	ADC Busy Extended Output (Live Time). ADCBX* represents the time the system cannot validly accept input pulses. When not in ACQUIRE mode, ADCBX* resides at +5V. (ADCBX* is intended to be used for live-time control.)
ACQ* (ENC*)	8	Acquire Input. Signal ACQ* should be at 0V to enable the LFC and ADC or +5V to disable the LFC and ADC. Input Impedance: 3 TTL loads shunted by 250 pF.
READY*	10	Ready Output. The steady state condition of signal READY* is +5V. Upon completion of a conversion, signal READY* goes to 0V to signal the MCA that data are ready to be transferred. On Output Current: Up to 24 mA.
GND	1,3,5,7,9,11	Logic Signal Common
BCB*	33	Buffer Converter Busy Output. From ADC
N.A.	27,28	Reserved.
Unused	29,30,31,32	Pass through from ADC connector unmodified

D. Abstract of Dr. Westphal’s Paper

The following abstract, presented at the 6th Modern Trends in Activation Analysis-Conference, Toronto, 1981, is reproduced, in part, with the permission of the author.

Westphal, G.P. (1981). Chem. 1982 Y. of Radioanal. AIAU 81303.

Real-Time Correction of Counting Losses in Nuclear Pulse Spectroscopy

G.P.Westphal (invited)
Atominstitut der Osterreichischen Universitaten, A-1020 Wien,
Austria

Abstract

Reviewing the current status of real-time correction of counting losses in nuclear pulse spectroscopy, the pileup problem is identified as the last question not resolved satisfactorily up to now. Correction of pileup losses is provided, at least in principle, by the classical pulse generator method, however, severe limitations in test frequency prohibit its application to real-time correction of counting losses. A solution is offered by the novel principle of the virtual pulse generator which obviates the shortcomings of the classical method simply by not introducing pulses into the spectroscopy system. Instead, the probability for pileup-free pulse processing is determined by suitable tests of the system status at arbitrarily high test frequencies.

After a discussion of the principles of the new method and its application to a real-time correction system experimental evidence is provided for the complete correction of counting losses of more than 98% under conditions of stationary as well as variable counting rates up to the limit of stable operation of the underlying spectroscopy system which is 800 000 c/s for an experimental high-rate gamma spectrometer.

Introduction

Activation analysis of short-lived isomeric transitions has been pioneered by Grass and coworkers with the installation of ultra-fast rabbit systems (1,2) at the institute’s TRIGA reactor. To fulfill the demands for quantitative pulse height analysis under conditions of rapidly varying counting rates and spectral shapes that are typical for the measurement of short-lived activation products several techniques for real-time correction of counting losses have been developed at our institute (3 - 5). They all have in common that, in contrast to conventional pulse height analysis, the channels that are addressed by the analog-to-digital converter are not incremented by one but are increased by a variable integer weighting factor taking into account the instantaneous counting loss situation.

The first of these methods that has been devised by J. Harms (3) derives the weighting factor from the number of pulses presented to the pulse height analyzer during subsequent analog-to-digital conversions, thus taking into account the dead-time losses caused by the pulse height analyzer. However, no compensation is provided for pulse pileup in the shaping amplifier which is the dominating reason for counting losses in modern spectrometers.

A substantial improvement took place with the introduction of the loss-free counting method (4,5). Here, the weighting factors are derived from the true integral counting rate that, by means of suitable real-time processors, is computed from dead-time and counting rate of a discriminator set slightly above the noise level of the system. In addition, the pulse height analyzer is protected by a pileup rejector that results in the distribution of the true integral counting rate according to the best possible approximation of the true spectral shape that is limited only by the finite pulse-pair resolution of the pileup rejector. Accordingly, the system behaves just as it would if subjected to the effect of a single very small dead-time equivalent to the pulse-pair resolution of the pileup rejector. Besides this inherent limitation which is finally due to the charge collection time of the detector, there are two more reasons that make it desirable not to rely on a pileup rejector for quantitative counting loss correction. First is the almost unavoidable dependence of the efficiency of the pileup rejector on the shape of the pulse amplitude distribution and second, more practical than systematical, the always present possibility of false triggering of the pileup rejector due to electrical interferences.

The only alternative for the complete correction of dead-time and pileup losses that does not depend on a fast amplification channel and a pileup rejector is the well-known and unanimously accepted pulse generator method that, by comparison of the number of test pulses introduced into the preamplifier of the system to the number of counts within the pulse generator peak of the measured spectrum, determines the probability of pileup-free pulse processing by the pulse height analyzer. The inverse of this probability is a correction factor providing complete counting loss compensation. Equally well-known are the drawbacks of the method, namely the necessity to place the pulse generator peak in a free region of the spectrum that prevents the application of the method in automatic data-taking systems, the corrections that are necessary to make up for the fact that test pulses cannot interfere with themselves and the contradictory demands on the frequency of the test pulse generator that should be low in order not to interfere too much with the detector pulses, and should be high to give good statistical accuracy. While a reasonable compromise may be found quite easily in most instances of long-lived samples and comparatively long measurement periods, this is not the case for an application of the method to real-time counting loss correction. Here, a new correction factor of sufficient statistical accuracy has to be provided every 1 to 10 milliseconds which would necessitate a test pulse generator frequency in the megacycle range.

From this dilemma the idea of the virtual pulse generator was originated, a new method of counting loss correction that, from a statistical point of view, is completely equivalent to the pulse generator but due to the fact that no pulses are introduced into the system is free from the above mentioned drawbacks and, especially, is not limited in test frequency. Instead of introducing actual test pulses into the system, the system status is tested periodically, if at a given instant a pulse could be introduced, if it could develop without pileup interference up to its peak and if it would find the pulse height analyzer not busy. Therefore, by means of a correlative test of the baseline of the shaping amplifier and the busy status of the analyzer, a complete emulation of the pulse generator method is possible that is limited in test frequency only by the speed of digital logic. Therefore, it is particularly well suited for real-time correction of counting losses.

Principles of the Virtual Pulse Generator Method

The classical pulse generator method that up to now was the only instrumental procedure providing complete counting loss correction, is based on the determination of a quantity referred to as the escape-acceptance probability or the combined probability of pulse pileup escape and pulse acceptance by the pulse height analyzer as the registration of a test pulse within the pulse generator peak of the measured spectrum. At the same time it confirms that the original pulse amplitude information has not been spoiled by pulse pileup, and that the pulse height analyzer has been free to accept the pulse for analysis. Exactly the same escape-acceptance probability is determined by the virtual pulse generator method; however, no additional pulses are introduced into or processed by the spectroscopy system, thus avoiding the shortcomings of the classical pulse generator method.

Instead, by inspection of signals already at hand in every modern spectroscopy system, namely the baseline of the shaping amplifier and the BUSY output of the pulse height analyzer, tests of the prerequisites for pileup-free pulse analysis are initiated periodically by a high-frequency digital clock. The prerequisite for a pulse to be free from pileup is the absence of interfering pulses during its pulse evolution time. This is the time from its rise above the noise level up to its peak or, more generally speaking, up to the instant of information transfer to the pulse height analyzer. The prerequisite for a pulse to be analyzed by the pulse height analyzer is met if the pulse height analyzer is not busy at the end of the pulse evolution time.

Therefore, a positive trial of the virtual pulse generator method, that is statistically equivalent to the successful registration of a test pulse in the classical pulse generator method, is given if no deviation from the quiescent level of the shaping amplifier's baseline is detected from the beginning of a test up to its end after one pulse evolution time, and if the pulse height analyzer is not busy at the end of the test. In a spectroscopy system of actual design with clean unipolar pulse response, the baseline of the shaping amplifier can be supervised by means of a discriminator set slightly above the noise level of the system. However, in case of bipolar pulse response both polarities have to be inspected.

Due to the fact that the status of the spectroscopy system is in no way influenced by the action of the virtual pulse generator, the baseline inspection periods can overlap each other, and new tests may be initiated by a clock having a period arbitrarily shorter than the pulse evolution time. In fact, the only limit to test frequency is the speed of digital logic, a circumstance that greatly enhances statistical accuracy and is a necessary prerequisite for the application of the method to real-time correction of counting losses.

Figure 10 reveals the surprising simplicity of one of the possible technical implementations of the virtual pulse generator. Here, a common SYSTEM BUSY has been derived from a logical OR between PULSE HEIGHT ANALYZER BUSY and AMPLIFIER BUSY that is the output of the previously mentioned baseline inspection discriminator. According to usual practice in pulse height analyzer design, pulse acquisition is initiated exclusively by the leading edge of SYSTEM BUSY, and preventing the analysis of pulses starting from a non-zero baseline or during the analysis of previous pulses. By means of a monostable multivibrator that is triggered by the trailing edge of SYSTEM BUSY and has a time constant of one pulse evolution time, SYSTEM BUSY is extended and employed to inhibit a high-frequency clock. It is evident that due to this gating action a clock pulse will be transmitted only if SYSTEM BUSY is not effective for at least one pulse evolution time, that is the necessary and sufficient prerequisite for pileup-free pulse analysis and, therefore, a positive trial of the virtual pulse generator. It is equally evident that the number of consecutively transmitted clock pulses corresponds to the number of positive trials resulting from overlapping inspection periods of the virtual pulse generator.

The escape-acceptance probability is given by the ratio of the number of positive trials or clock pulses transmitted by the gating circuit to the total number of trials or clock pulses applied to the gating circuit.

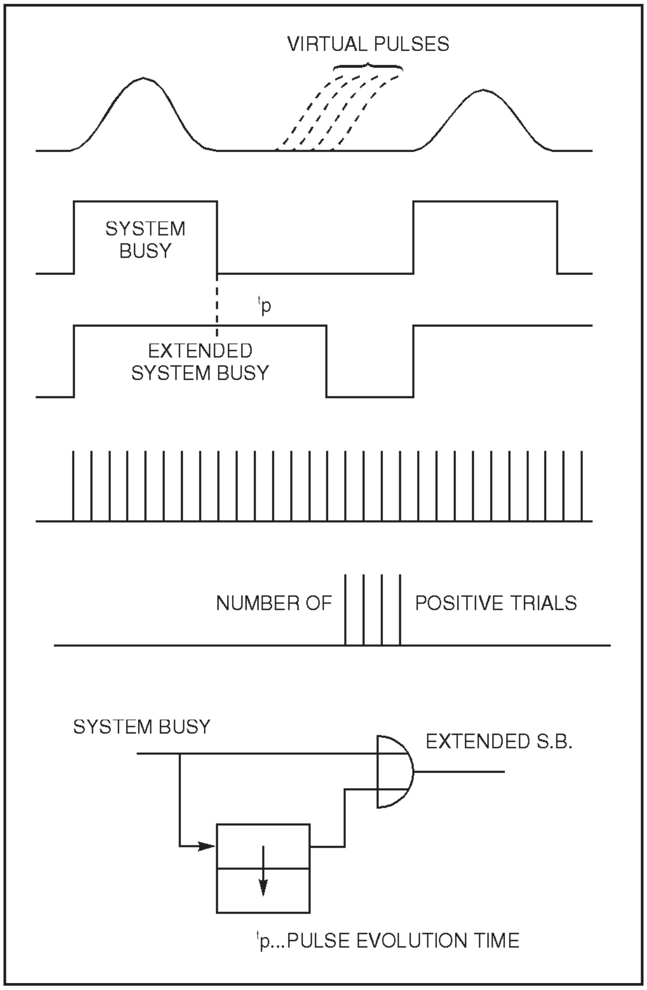

Figure 10 Functional Principal of the Virtual Pulse Generator

Correction of Counting Losses at Stationary Counting Rate

Besides its primarily intended application to real-time correction of counting losses, the virtual pulse generator method also offers some interesting possibilities for the correction of counting losses under conditions of stationary counting rates. First is a minor substitution of the classical pulse generator method where the counting losses of a measurement are corrected by a multiplication of the results (channel contents or peak areas) by the inverse of the escape-acceptance probability.

However, significant advantages over the classical method result from the action of the virtual pulse generator, primarily an unbiased estimate of the escape-acceptance probability that is not disturbed by intermixed generator pulses, and is of substantially enhanced statistical accuracy due to an arbitrarily high test frequency, the direct registration of the escape-acceptance probability by means of digital counters instead of the sometimes problematic pulser peak area evaluation (6), and finally no need to care for the spectral position of a pulser peak that makes the procedure more suitable for unattended data acquisition.

Probably even more attractive is the application of the virtual pulse generator method to the correction of counting losses by means of an automatic extension of measurement time similar to the principle of the live-time clocks that can be found in many modern pulse height analyzers. A live-time clock is composed of a quartz-stabilized clock, and a gating circuit transmitting clock pulses to a preset counter only during the live-time intervals of the pulse height analyzer. Therefore the time required by the counter to reach its preset value is extended and, in return, is equivalent to the duration of the measurement, in inverse proportion to live-time. By replacing live-time by escape-acceptance probability or, more technically speaking, by substituting the original gating signal of the live-time clock by the proper EXTENDED SYSTEM BUSY signal of the virtual pulse generator almost every pulse height analyzer can be transformed into an instrument that is suited for loss-corrected precision counting of long-lived samples.

Real-Time Correction of Counting Losses

The virtual pulse generator method is particularly well suited for real-time correction of counting losses as it enables the generation of consecutive weighting factors W(t), of sufficient statistical accuracy within millisecond intervals, by virtue of an arbitrarily high test frequency. These weighting factors, that are short-time samples of the inverse of escape-acceptance probability, are produced by counting the total number of trials required for a predetermined number of positive trials of the virtual pulse generator.

Figure 11 shows a real-time counting loss correction unit that is based on known principles. SYSTEM BUSY which is derived from a logical OR between the busy signals of the pulse height analyzer, the amplifier's baseline inspection discriminator, and the preamplifier's reset generator is extended for one pulse evolution time by means of a trailing-edge-triggered monostable multivibrator. It is subsequently used to inhibit a digital clock of a frequency of 4 MHz. The transmitted clock pulses corresponding to the number of positive trials are counted with the aid of a binary counter C1(a) having a length of a bit.At the same time, the non-gated clock pulses corresponding to the total number of trials are recorded by means of a cascaded binary counter consisting of parts C2(a) and C2(A) of a length of (a) and (A) bit, respectively. After the registration of 2^a positive trials that is indicated by an overflow of counter C1(a) the contents of C2(a) and C2(A) are transferred to parallel storage registers L(a)and L(A) and counters C2(a) and C2(A) are cleared and subsequently reinitiated. By that means, consecutive weighting factors W(t) are produced in an integer-fractional representation A.a, integer and fractional parts being stored in L(A) and L(a), respectively. In order to be compatible with purely integer memory organization of usual pulse height analyzers the weighting factors are transformed to integers by means of a simple algorithm. After transferring the integer part of a weighting factor to the pulse height analyzer its fractional remainder is added to the next weighting factor by means of a parallel binary adder, thus performing a running integer approximation of the true weight at the expense of a certain increase in the amount of statistical fluctuation.

In the given implementation numerical precision is 8-bit both for A and a, corresponding to a maximum weighting factor of 255 and a preset value of 256 for the number of positive trials. This has been found to be a very reasonable compromise in statistical accuracy as well as in the speed of weighting factor renewal. The interval of time that is required for the determination of a new weighting factor is given by the product of test frequency, preset value of positive trials, and instantaneous weighting factor and is W(t) [64 µs for the described loss correction unit].

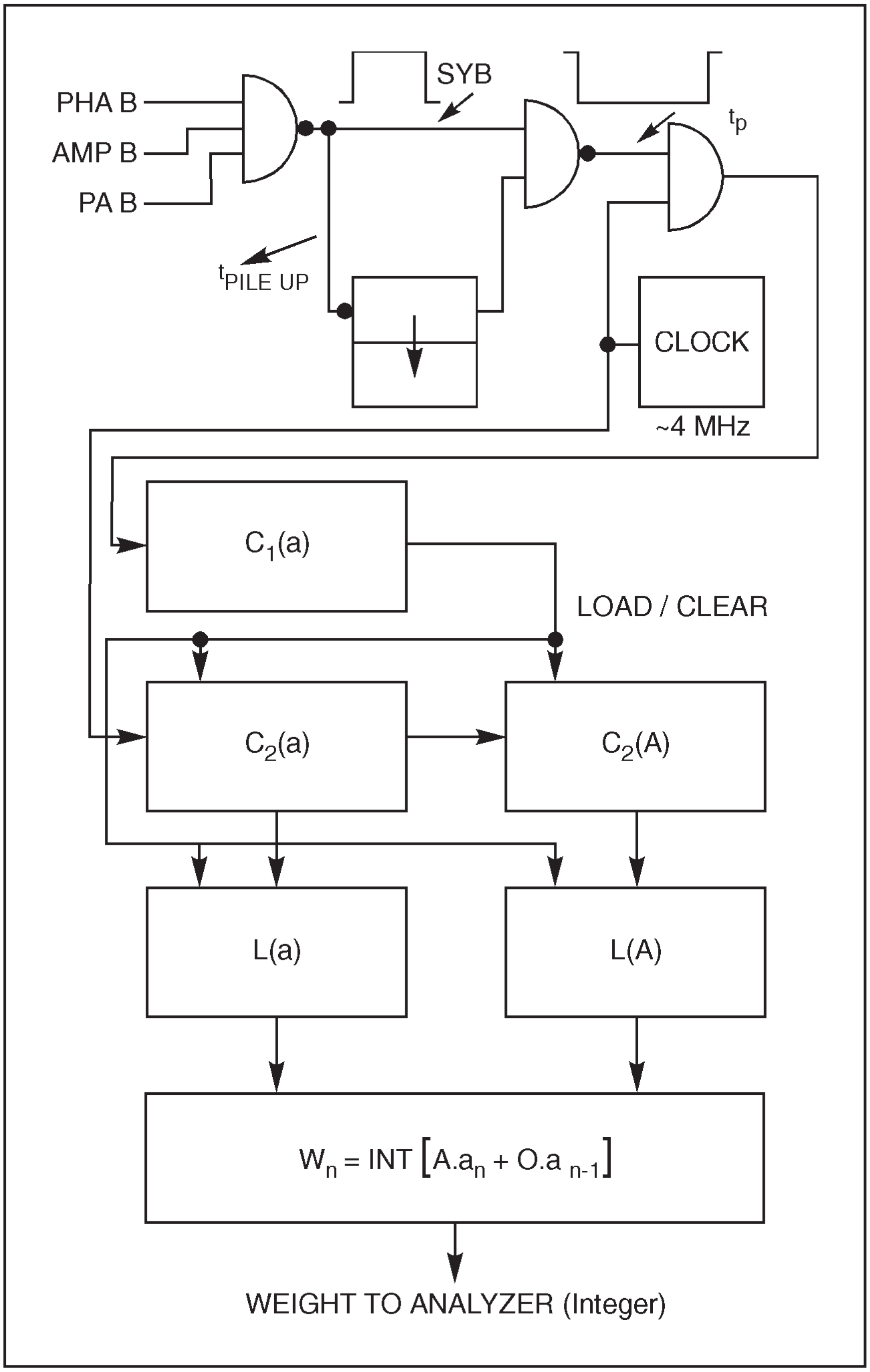

Figure 11 Block Diagram of a Real-Time Loss-Correction Unit Based on the Virtual Pulse Generator

Statistical Errors

The statistical error of the channel content M of a spectrum measured with real-time correction of counting losses, essentially depends on the number N of analog-to-digital conversions going into that channel and can be described by the following. (5)

$$\left[\frac{dM}{M}\right]^2 = \left[\frac{dN}{N}\right]^2 + \frac{1}{N}\left[\frac{dW}{W}\right]^2$$

Where dW/W is the relative statistical error of the weighting factors. Under the reasonable assumption of Poisson statistics for the number N of analog-to-digital conversions the total relative error dM/M can be rewritten as:

$$\frac{dM}{M} = \frac{1}{\sqrt{N}}\sqrt{\left[1+\left[\frac{dW}{W}\right]^2\right]}$$

illustrating the increase over the basic relative error that is caused by the correction procedure.

The relative error of the classical pulse generator method of counting loss correction has been given by Deighton (7,8)

$$RE = \sqrt{\frac{T_D}{T_L T_C\ r}}$$

where T_D is dead time, T_L is live-time, T_C is counting time and r the frequency of the pulse generator. Consequently, in the limit of high counting losses, the relative error of weighting factors of the virtual pulse generator may be estimated as

$$RE \approx \sqrt{\frac{W}{T_c\ r}}$$

where $T_C r$ is the preset value of positive trials. Numerical examples of dW/W (W,T_Cr) for different weighting factors and preset values are given below together with the corresponding total relative error dM/M:

$$\frac{dW}{W}\ (10,256) = 19\%; \qquad \frac{dM}{M} = \frac{1}{\sqrt{N}} \times 1.02$$

$$\frac{dW}{W}\ (100,256) = 63\%; \qquad \frac{dM}{M} = \frac{1}{\sqrt{N}} \times 1.18$$

$$\frac{dW}{W}\ (10,4096) = 5\%; \qquad \frac{dM}{M} = \frac{1}{\sqrt{N}} \times 1.001$$

$$\frac{dW}{W}\ (100,4096) = 16\%; \qquad \frac{dM}{M} = \frac{1}{\sqrt{N}} \times 1.01$$

An experimental determination of the standard deviation of weighting factors by direct comparison of simultaneously measured loss-corrected and non-corrected spectra[1] according to the formula for the variance of grouped data

$$\sigma_W = \frac{\sum^n N_i \left(\frac{M_i}{N_i} - \overline{W} \right)^2}{(n-1)}$$

$$\overline{W} = \frac{\sum^n M_i}{\sum^n N_i}$$

$$\mathrm{RE} = \frac{\sigma_W}{\overline{W}}$$

where M_i and N_i are the contents of corresponding loss-corrected and non-corrected channels. This results in considerably lower relative errors. For example, $dW/W_{ex}(60,256) = 18\%$ vs. $dW/W_{est}(60,256) = 48\%$.

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[1] The simultaneous measurement of loss-corrected and non-corrected spectra enables the convenient assessment of statistical errors under conditions of variable counting rates and spectral shapes (5) and, therefore, is an option on our spectroscopy system.

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E. Model 703072 Dual Spectrum LFC Option

The Model 703072 Dual Spectrum LFC (DSL) Option is a piggy-back board that mounts inside a Model 599 LFC module to provide dual-spectrum (corrected and uncorrected) capability. The DSL board is functionally (and electrically) placed between the 599 LFC and the MCA system. It will pass the LFC's corrected spectrum to the MCA and additionally generate an uncorrected spectrum. This second spectrum will be placed in a group of channels immediately above the corrected spectrum.

Controls

The board is configured by on-board dip switches and jumpers. Refer to Figure 12.

ADC Conversion Range

Set only one switch on U2 to the desired ADC Conversion Range: 32k, 16k, 8k, 4k, 2k, 1k, 512, or 256. Select a Range which is one-half of the MCA's memory range selection. This automatically sets the address offset for storage of the uncorrected spectrum.

Mode

In Dual Spectrum mode (U8 Switch 1 ON), the corrected spectrum is stored in the first memory segment and the uncorrected spectrum is stored in the channel group directly above.

In Transparent mode (U8 Switch 1 OFF) the DSL passes all data through.

ADC Transfer Type

Add-N mode (U8 Switch 2 ON) is for MCAs capable of performing ADD-N LFC storage (AccuSpec/B or 556 AIM).

Multiple Add-1 (U8 Switch 2 OFF) is for LFC operation with MCAs that do not function in the Add-N mode (System 100).

Note: Be sure to select the corresponding STD/MPX jumper on the Model 599 LFC's board as well.

In order to have the Dual LFC software properly analyze the spectra, the LT DISABLE jumper on the LFC board must be removed.

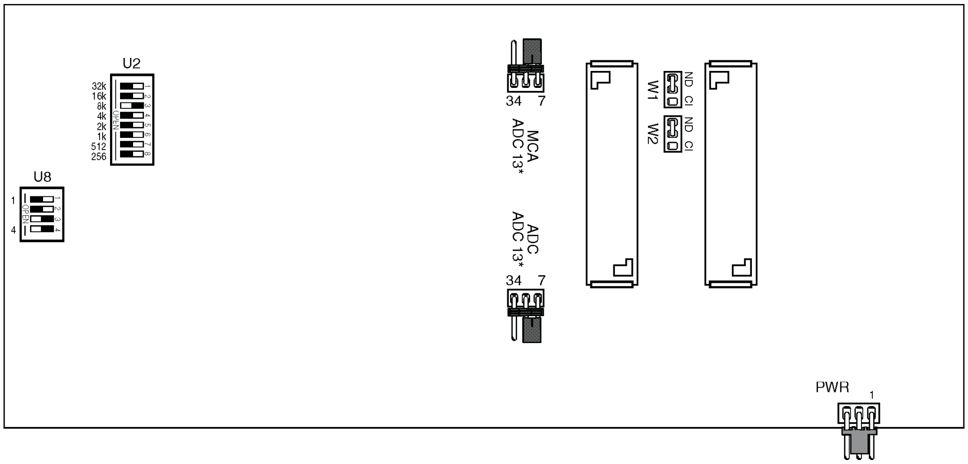

Figure 12 Locating the DSL Board's Controls

ADC-ADC13* Jumper

Connects the DSL ADC13 address line from either the ADC A13 address line (Position 7) or the ADC A13X address line (Position 34). All standard Canberra ADCs use position 7.

MCA-ADC13* Jumper

Connects the DSL ADC13 address line to either the MCA A13 address line (Position 7) or the MCA A13X address line (Position 34). Position 7 is used with the AccuSpec/B and System 100; Position 34 is used with the 556 AIM.

MCA Interface Type

MCA handshake type. Use ND (U8 Switch 4 OFF) for AccuSpec/B or 556 AIM; use CI position (U8 Switch 4 ON) for System 100.

MCA-ADCB Polarity

Solder jumper selecting polarity of the ADC Busy output to MCA. W1 to ND (negative) for AccuSpec/B and 556 AIM, or W1 to CI (positive) for S100.

MCA-ACQ Polarity

Solder jumper selecting polarity of the MCA Enable Conversion input from MCA. W2 to ND (negative) for AccuSpec/B and 556 AIM, or W2 to CI (positive) for System 100.

Field Installation

To install the 703072 DSL Option in an existing 599 LFC Module, perform the following steps.

1. Remove the screws holding both side covers.

2. With the left side (solder side) of the 599 LFC module up, remove the two 6-32 screws holding the top of the 599 LFC printed circuit board to the NIM wrap. Do not remove the lower two screws.

3. Cut the cable tie holding the MCA and ADC ribbon cables to the rear panel wrap. Disconnect the ribbon cables from the MCA and ADC connectors on the 599 LFC printed circuit board. Save these cables in case you want to remove the option board at some future date.

4. Place the DSL board over the 599 LFC board so that the ADC and MCA headers line up with the MCA and ADC connectors on the 599 LFC printed circuit board. It is possible to misalign the DSL and 599 LFC board by one connector, but if the top spacers on the DSL board align with standoffs on the main 599 LFC board, the board is properly aligned.

5. Firmly press the two boards together.

6. Using the two 4-40 screws supplied, attach the DSL board to the 599 LFC board and NIM wrap through the top two standoffs. Using the cable tie provided, tie the ribbon cables on the DSL board to the rear panel wrap.

7. Locate the 3-pin power connector (has one purple wire on the center pin). Cut the cable tie securing the connector wire to the bottom of the module.

Note The 599 LFC modules shipped prior to January 1, 1995 had the power connector and wire shipped separately. If you are trying to install the DSL board in one of these older units, call the factory to receive the wire assembly and installation instructions.

8. Slide the power connector onto the PWR connector on the DSL board.

9. Connect the ribbon cables from the MCA and ADC to the labeled connectors coming from the DSL board.

F. Installation Considerations

This unit complies with all applicable European Union requirements.

Compliance testing was performed with application configurations commonly used for this module; i.e. a CE compliant NIM Bin and Power Supply with additional CE compliant application-specific NIM were racked in a floor cabinet to support the module under test.

During the design and assembly of the module, reasonable precautions were taken by the manufacturer to minimize the effects of RFI and EMC on the system. However, care should be taken to maintain full compliance. These considerations include:

- A rack or tabletop enclosure fully closed on all sides with rear door access
- Single point external cable access
- Blank panels to cover open front panel Bin area
- Compliant grounding and safety precautions for any internal power distribution
- The use of CE compliant accessories such as fans, UPS, etc.

Any repairs or maintenance should be performed by a qualified Canberra service representative. Failure to use exact replacement components, or failure to reassemble the unit as delivered, may affect the unit's compliance with the specified EU requirements.

Request for Schematics

Schematics for this unit are available directly from Canberra. Write, call or FAX:

Training and Technical Services Department
Canberra Industries
800 Research Parkway, Meriden, CT 06450
Telephone: (800) 255-6370 or (203) 639-2467
FAX: (203) 235-1347

If you would like a set of schematics for this unit, please provide us with the following information.

Your Name ____

Your Address ____

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Unit’s model number __________________________

Unit’s serial number __________________________

Note: Schematics are provided for information only; if you service or repair or try to service or repair this unit without Canberra’s written permission you may void your warranty.

Canberra's product warranty covers hardware and software shipped to customers within the United States. For hardware and software shipped outside the United States, a similar warranty is provided by Canberra's local representative.

DOMESTIC WARRANTY

Canberra (we, us, our) warrants to the customer (you, your) that equipment manufactured by us shall be free from defects in materials and workmanship under normal use for a period of one (1) year from the date of shipment.

We warrant proper operation of our software only when used with software and hardware supplied by us and warrant that our software media shall be free from defects for a period of 90 days from the date of shipment.

If defects are discovered within 90 days of receipt of an order, we will pay for shipping costs incurred in connection with the return of the equipment. If defects are discovered after the first 90 days, all shipping, insurance and other costs shall be borne by you.

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EXCEPT AS SET FORTH HEREIN, NO OTHER WARRANTIES, WHETHER STATUTORY, WRITTEN, ORAL, EXPRESSED, IMPLIED (INCLUDING WITHOUT LIMITATION, THE WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE) OR OTHERWISE, SHALL APPLY. IN NO EVENT SHALL CANBERRA HAVE ANY LIABILITY FOR ANY SPECIAL, INDIRECT OR CONSEQUENTIAL LOSSES OR DAMAGES OF ANY NATURE WHATSOEVER, WHETHER AS A RESULT OF BREACH OF CONTRACT, TORT LIABILITY (INCLUDING NEGLIGENCE), STRICT LIABILITY OR OTHERWISE.

EXCLUSIONS

Our warranty does not cover damage to equipment which has been altered or modified without our written permission or damage which has been caused by abuse, misuse, accident or unusual physical or electrical stress, as determined by our Service Personnel.

We are under no obligation to provide warranty service if adjustment or repair is required because of damage caused by other than ordinary use or if the equipment is serviced or repaired, or if an attempt is made to service or repair the equipment, by other than our personnel without our prior approval.

Our warranty does not cover detector damage due to neutrons or heavy charged particles. Failure of beryllium, carbon composite, or polymer windows or of windowless detectors caused by physical or chemical damage from the environment is not covered by warranty.

We are not responsible for damage sustained in transit. You should examine shipments upon receipt for evidence of damage caused in transit. If damage is found, notify us and the carrier immediately. Keep all packages, materials and documents, including the freight bill, invoice and packing list.

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