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**User Manual for the
Q-5485, 1.0-nsec Fast Preamplifier
and
Q-5487, 1.0-nsec Fast Amplifier**

K. Rush

OAK RIDGE NATIONAL LABORATORY
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INSTRUMENTATION AND CONTROLS DIVISION

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AND
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ABSTRACT

An amplifier system (Q-5485 and Q-5487) with a rise time of 1.0 nsec was developed for service in nuclear event detectors that require a high timing resolution. Because of its lower cost, greater reliability, lower noise, and higher gain bandwidth, this system is expected to replace other amplifier systems commonly used in this service. Simplified circuitry, improved transistors, and hybrid microcircuit fabrication yield small, high-performance amplifiers that are compatible with existing 50- Ω transmission components. Solid metal packaging eliminates radio-frequency interference and ground-loop pickup; it also provides convenient handling and protection of the circuit.

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1. DESCRIPTION

1.1 General

The Q-5485, 1.0-nsec Fast Preamplifier and the Q-5487, 1.0-nsec Fast Amplifier provide 30 dB of power gain for fast, voltage- or current-transducer pulses while they preserve the shape and resolution of the pulses. The amplifier inputs and outputs are compatible with 50- Ω transmission systems, and their low reflection coefficients reduce measurement errors introduced by reflected pulses. The circuit is stable against oscillations for any combination of complex, load or source impedances and allows pulses from capacitive or inductive sources to be transmitted over 50- Ω cable before amplification.

1.2 Construction

A small, solid-metal package, along with power supply filtering inside the amplifier eliminate radio-frequency interference and ground-loop pickup between different amplifiers connected to the same power source. Several amplifiers mounted near a small multitransducer or in a common chassis therefore produce negligible crosstalk.

The Fast Preamplifier, Q-5485 (Fig. 1), is a stand-alone preamplifier. It has a quick-disconnect power connector and a BNC input connector to mechanically support the preamplifier when it is mounted on a remote transducer system. The Fast Amplifier, Q-5487 (Fig. 2), has solder-pin power connections and tapped holes for mounting it with machine screws to a chassis ground plane. All other connections are made with Lemo type coaxial connectors.

The circuits of the two amplifiers are similar. The preamplifier generates less noise than that generated by the amplifier and accepts a test-signal input.

Fig. 1. Q-5485 1.0-nsec fast preamplifier

Fig. 2. Q-5487 1.0-nsec fast amplifier

1.3 Applications

Designed specifically to amplify very small current pulses from nuclear fission ionization chambers, these amplifiers find a broad range of applications in pulse and continuous wave systems that require broad-band, low-noise amplification, such as amplification of pulses from photomultiplier tubes or solid-state radiation detectors and preamplification of radio-frequency antenna signals.

1.4 Specifications

Tables 1 and 2 give typical electrical and mechanical characteristics of the two amplifiers.

These amplifiers can presently be built by ORNL at an estimated cost of under \$300 each for 20 units.

Table 1. Electrical characteristics

Specification	Q-5485	Q-5487
Rise time (10-90%), nsec	1.0	1.0
Square pulse droop, %/ μ sec	10	10
Settling time to 2%, nsec	3	3
Gain, dB	30	30
Gain stability, %/ $^{\circ}$ C	0.2	0.2
Input noise voltage, $nV/\sqrt{Hz}$	0.5	0.5
Input noise current, $pA/\sqrt{Hz}$	7.0	10.0
Nonlinearity, %	1.0	1.0
Positive output pulse range, V	+0.5	+0.5
Negative output pulse range, V	-2.0	-2.0
Power supply voltage, V dc	± 12	± 12
Power supply current, mA dc	± 20	± 20

Table 2. Mechanical characteristics

Specification	Q-5485	Q-5487
Length, cm	7.4	5.8
Width, cm	3.1	3.4
Depth, cm	1.33	1.33
Weight, g	52	48
Connectors		
Input	BNC	Lemo
Output	Lemo	Lemo
Test	Lemo	NA
Power	Four-pin Lemo	Solder Pins

1.5 Applicable Drawings

The following list gives the ORNL Instrumentation and Controls Division drawing numbers and subtitles for the Q-5485, 1.0-nsec Fast Preamplifier:

1. Q-5485-1 Circuit Diagram
2. Q-5485-2 Mechanical Details
3. Q-5485-3 Metalphoto Decal
4. Q-5485-4 Component Layout
5. Q-5485-5 Parts List.

The following list gives the ORNL Instrumentation and Controls Division drawing numbers and subtitles for the Q-5487, 1.0-nsec Fast Amplifier:

1. Q-5487-1 Circuit Diagram
2. Q-5487-2 Mechanical Details
3. Q-5487-3 Metalphoto Decal
4. Q-5487-4 Component Layout
5. Q-5487-5 Parts List.

2. THEORY OF OPERATION

2.1 General

The two-stage, common-emitter circuits in the Q-5485 and Q-5487 amplifiers are constructed with thick-film hybrid microcircuits (Fig. 3). As a result, these devices have a small size, high speed, and good mechanical integrity. Because of the high gain and low noise available at high frequencies with bipolar transistors, the construction of these amplifiers is simple, using only two active devices. Shunt and series feedback set the gain, the input impedance, and the output impedance of each stage. DC feedback controls the bias, ensuring gain stability.

2.2 Circuit Operation

Figures 4 and 5 are schematic diagrams of the Q-5485 and Q-5487 amplifier circuits. Input pulses coupled through C_1 are amplified and inverted by Q_1 . Resistor R_1 controls the gain of Q_1 , and R_2 controls the input impedance. Capacitor C_2 couples pulses from Q_1 into Q_2 for further amplification and another inversion. The gain and the input impedance of Q_2 are controlled by R_5 and R_6 , respectively. The output pulses from Q_2 are coupled through C_7 and C_{10} . Coils L_1 , L_2 , and L_3 peak the high-frequency gain, R_3 and R_7 set the dc bias currents, and R_4 and R_8 set the bias voltages. The transistor collectors are biased at ~ 6 V dc and 10 mA.

Resistors R_{10} and R_{11} and capacitors C_5 and C_6 filter the power supply lines at high frequencies.

Capacitors C_3 , C_4 , C_8 , and C_9 provide ac bypass for the transistor emitters. Base bias current flows from ground through R_9 , R_6 , and L_3 to the base of Q_2 and on through L_2 , R_2 , and L_1 to the base of Q_1 . The base of Q_2 sets at approximately -0.8 V dc; the base of Q_1 sets at approximately -0.9 V dc. The emitter voltages of Q_2 and Q_1 are approximately -1.5 V dc and -1.6 Vdc, respectively.

Diode D_1 provides protection from large negative input pulses that might damage the input transistor.

Fig. 3. Q-5485 circuit photograph

Fig. 4. Q-5485 1.0-nsec fast preamplifier circuit diagram

Fig. 5. Q-5487 1.0-nsec fast amplifier circuit diagram

3. OPERATING INSTRUCTIONS

3.1 Installation

Because of its small size, the Q-5485 preamplifier can be mounted near a signal source, which avoids transmission of small signals over coaxial cables. The input BNC connector provides mechanical support and good input grounding for a preamplifier mounted on a rigid signal transducer.

Cables connect the output, test input, and power inputs to an experiment station where power supplies and further signal processing equipment are located. A chassis at the experiment station can contain Q-5487 amplifiers and shaping filters, as needed.

Both the preamplifier and the amplifier use ± 12 V dc power supplies. The preamplifier receives power via a Lemo type four-pin connector. Positive 12 V dc should be on pin 1 of the mating connector, and negative 12 V dc should be on pin 4. The power-to-ground connection is made through the connector shell to the amplifier case.

The Q-5487 amplifier receives power via two solder pins on the side of its case. The pin closest to the input connector should have negative 12 V dc applied, while the pin closest to the output connector should have positive 12 V dc applied. The power-to-ground connection is made by mounting the amplifier on a power ground plane.

Signals are coupled into the preamplifier by a male BNC connector. A 1-k Ω test input is also provided via a female Lemo coaxial connector (Fig. 1). The test pulse should be preshaped and back-terminated at the pulse source to avoid reflections. A female Lemo coaxial connector couples signals into the Q-5487 amplifier.

The pulse outputs from the Q-5485 and Q-5487 units are coupled through female Lemo coaxial connectors into a 50- Ω cable transmission system. The output cable should be terminated in 50 Ω for proper gain calibration.

3.2 Operation

There are no operation controls or adjustments to be made on either of the Q-5485 or Q-5487 units; however, there are some precautions to be observed.

Voltages in excess of ± 50 V dc should be avoided on either the input or the output.

Since the gain of either unit is a function of negative supply voltage, the negative supply should be very stable. A variable negative supply can be used to make slight adjustments in gain. Positive-supply variations have relatively little effect on the performance of either unit. Neither supply should exceed 24 V dc.

4. MAINTENANCE

4.1 General

Other than periodic cleaning of connector contacts, the Q-5485 and Q-5487 amplifiers should require no maintenance. However, if an amplifier should fail, the circuit can be repaired by a qualified hybrid microcircuit technician. Replacement components should correspond to the replaceable parts list, Sect. 5.

4.2 Troubleshooting

With the amplifier cover removed, power applied, and both input and output terminated in $50\ \Omega$, the voltages from the amplifier case to the collectors of Q_1 and Q_2 are checked using a high-impedance voltmeter. These voltages should be 6 ± 1 V dc. If the collector voltage is outside this range and the ± 12 V dc power supplies are correct, the associated transistor is probably defective.

5. REPLACEABLE PARTS

A listing and description of all replaceable parts is given in Table 3.

Table 3. Replaceable parts list

Part No.	Description
C ₁ , C ₁₀	Capacitor, 0.1 μ F, $\pm 20\%$, 50 V, ceramic, USCC No. CS20-C-104-M
C ₂ , C ₃ , C ₇ , C ₈	Capacitor chip 0.1 μ F, $\pm 20\%$, 50 V, ceramic, USCC No. W-050-FH-104-MP
C ₅ , C ₆	Capacitor chip, 0.47 μ F, $\pm 20\%$, 50 V, ceramic, USCC No. W-050-LL-474-MP
C ₄ , C ₉	Capacitor chip, 3.3 μ F, $\pm 10\%$, 25 V dc, tantalum, Sprague No. 194D335X9035F3
S1	Ceramic, thick-film substrate, ORNL I&C TF21-2
R ₈	Resistor, 1.0 k Ω , $\pm 5\%$, 1/8 W, carbon, Allen Bradley
R ₁₂ , R ₁₃ (for Q-5485 only)	Resistor, 510 Ω , $\pm 5\%$, 1/8 W, carbon, Allen Bradley
Q ₁ (for Q-5485)	Transistor, NPN, 5 GHz, Beta, 70-200, Ampercx, BFR93 (selected)
Q ₁ (for Q-5487), Q ₂	Transistor, NPN, 5 GHz, Beta, 20-70, Ampercx, BFR93 (selected)

6. ACCEPTANCE TESTS

6.1 General

To be acceptable, the Q-5485 and Q-5487 amplifiers must pass tests of the following parameters: gain accuracy, gain flatness, rise time, and input reflection. After an initial calibration of the pulser and oscilloscope, these amplifier parameters are measured using one setup. Gain accuracy is determined by applying a known input pulse and measuring the resulting output pulse height. Normalization of this output pulse

leads to relative measures of the gain flatness, rise time, and input reflection.

6.2 Test Instruments

The following test equipment is required:

1. A dual, ± 12 V dc regulated power supply.
2. A pulse generator and 50- Ω attenuator set that is capable of generating a 100-mV pulse with a rise time of less than 1.0 nsec and a width of greater than 1.0 μ sec.
3. An oscilloscope, either real time or sampling, with a rise time of less than 1.0 nsec. The overshoot and aberrations of the oscilloscope and pulse generator should be less than 2%.
4. Assorted 50- Ω cables, connectors, and adapters as needed.
5. A special, 1-k Ω , series cable terminator to simulate a high impedance source (Appendix, Sect. 7).

6.3 Oscilloscope and Pulser Calibration

The following is a step-by-step procedure for verifying the calibration of the oscilloscope and pulser.

1. Connect the pulse generator, attenuator set, 1-k Ω terminator, and 50- Ω input oscilloscope, using 50- Ω cables as shown in Fig. 6.
2. With the oscilloscope set at 2 mV/div and 100 nsec/div, adjust the trigger and the pulser output to obtain a stable display.
3. Adjust the pulser controls and attenuators to set the pulse height at 5 div (10 mV).
4. All aberrations on the pulse should be less than 0.2 division from 1.0 nsec to 1.0 μ sec.
5. If the aberrations are not within one minor division, adjust the pulser or oscilloscope, or replace either or both for these tests.
6. Change the oscilloscope horizontal control to 1 nsec/div, and measure the 10 to 90% rise time of the test pulse.
7. The rise time of the test pulse should be less than 1 nsec.

6.4 Amplifier Tests

The following test procedure will verify the Q-5485 and Q-5487 amplifier performance, if the pulser and oscilloscope combination passed steps 4 and 7 above:

1. Connect the pulse generator, attenuator set, 1-k Ω terminator, Q-5485 or Q-5487 amplifier, ± 12 V dc power supply, and oscilloscope as shown in Fig. 7.
2. With amplifier power on and the oscilloscope set to 100 mV/div and 10 nsec/div, adjust the trigger to obtain a stable display. A display similar to the one shown in Fig. 8 should be obtained.
3. Approximately 35 nsec after the initial transition, there will be reflection aberration, which can be either positive or negative and can cause a net shift in the trace after that point. The measured gain for this test will be the ratio of output pulse height at 30 nsec to the amplitude of the test pulse of 10 mV.
4. If the output pulse is between 2.8 and 3.6 divisions, the amplifier will have an acceptable gain of 30 ± 1 dB.
5. By using the variable volts/div control on the oscilloscope, normalize the output pulse height to 5 div at 30 nsec.
6. If the reflection and net shift in pulse height after 35 nsec is less than 1/2 division, the amplifier will have an acceptable reflection of less than $\pm 10\%$.
7. Change the oscilloscope time scale to 1.0 nsec/div, and measure the 10 to 90% rise time of the output pulse. This should be less than 1.5 nsec total for the amplifier, pulse generator, and oscilloscope.
8. Change the oscilloscope time scale to 100 nsec/div, and measure the droop from 100 nsec to 1.0 μ sec. The droop should be less than 15%, or 3/4 division to be acceptable.

ORNL-DWG 78-5493

Fig. 6. Oscilloscope and pulser calibration setup

ORNL-DWG 78-5492

Fig. 7. Amplifier test setup

ORNL-PHOTO 1113-78

Fig. 8. Typical amplifier test output pulse

7. APPENDIX

A 1-k Ω terminator can be built in a standard Pomona Electronics Co., BNC component carrier box. Four, 250- Ω resistors in series are preferred to a single 1-k Ω resistor to reduce the end-to-end capacitance of the terminator. At least one Faraday shield around the resistors is recommended, also. Figure 9 is a schematic diagram of the terminator,

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Fig. 9. Schematic diagram of a 1-k Ω terminator

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