DLTS Measurements with Boonton Model 7200 Capacitance Meter

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Introduction

The Boonton Model 7200 Capacitance Meter is a precision, high-speed instrument used to measure the capacitance of semiconductor devices and passive components. One application for the Model 7200 is the measurement of Deep Level Transient Spectroscopy, or DLTS. This application note provides guidelines for using the Model 7200 in a DLTS system; it analyzes several ways of generating pulse bias and presents examples of the measurement capabilities of the Model 7200.

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The DLTS Measurement

DLTS involves the analysis of junction capacitance versus time following a bias pulse. The measurement setup consists of the capacitance meter, a bias pulse generator, a digitizer and a computer as shown in Figure 1.

The bias supply provides a bias voltage across the device under test (DUT) which is adjustable in both amplitude and duration. Control of the pulse transition time (rise and fall time) is also desirable. The range of bias voltage and pulse period varies by application.
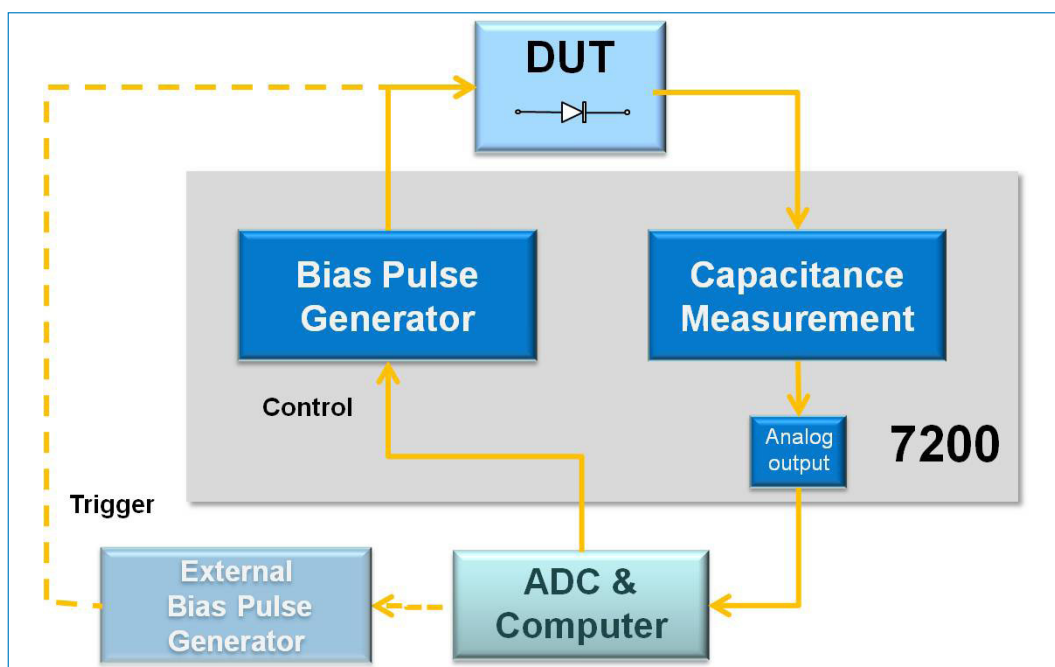

Figure 1. Typical DLTS Measurement System

Boonton 7200 Capacitance meters have the capability to provide variable bias pulses. If more flexibility in pulse generation is needed, the market offers a variety of suitable pulse generators. Just to mention a few: Agilent 81101A, 81104A or 81110A and Picosecond Models 12000, 12010 or 12020 are all suitable for this test.

The heart of the test setup is the Boonton 7200 capacitance meter with its analog output. This output presents a calibrated, real time reference voltage proportional to the capacitance of the semiconductor under test.

The 7200 is fully backwards compatible with the older Boonton 72EA, for which many DLTS systems have been designed. The 7200 has however an improved response time, overload recovery and improved signal-to-noise ratio.

Figure 2 shows a simplified block diagram of the measurement circuits of the Model 7200. The 7200 uses a wideband amplifier with high-speed clamping circuitry, providing faster overload recovery. Improved shielding of the measurement circuitry reduces noise and digital interference at the analog output. Transition time is typically less than 25 us.

The test and differential connections, consisting of HI inputs, DIFF and TEST, are connected together inside the 7200, and the center-tapped secondary of an isolation transformer generates the differential 1 MHz test signals at the LOW output connectors. The capacitance measurement can be normalized by connecting a compensating capacitor onto the differential terminals, or by zeroing the measurement using the ZERO key.
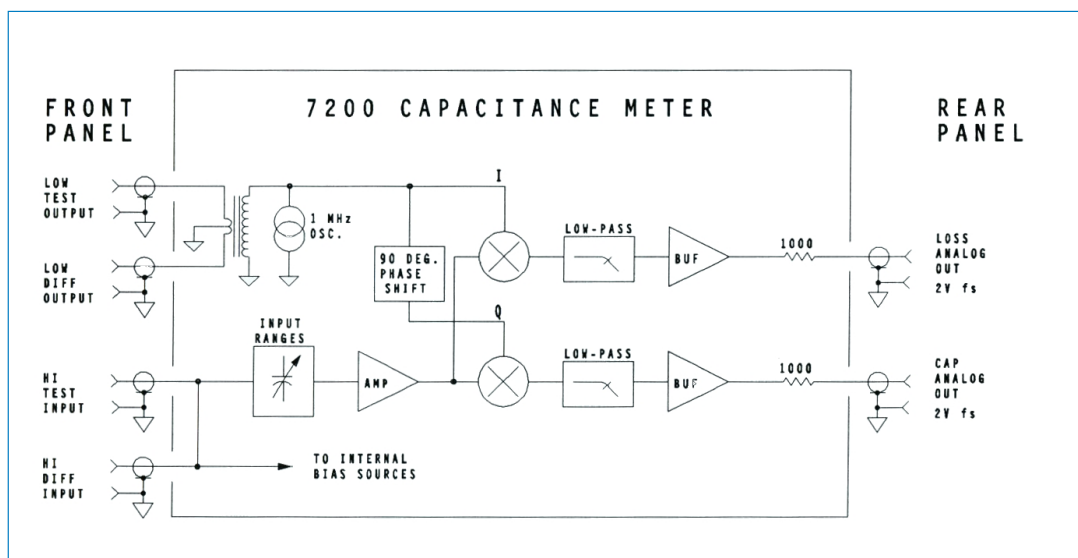
Figure 2. Block Diagram of Measurement Circuits

Capacitance of up to ±2000 pF can be zeroed with a single keystroke. Adding a compensating capacitor onto the differential terminals allows the instrument to operate on an even more sensitive capacitance range.

The Model 7200 has two features that greatly simplify DLTS measurements: a programmable internal bias supply and an external bias measurement function. The internal bias supply voltage range is ± 60 volts and is settable from either the front panel or over the IEEE-488 interface bus. Externally applied bias voltages are measured and displayed by the 7200, which eliminates the need for an additional digital volt meter (DVM). Figure 3 shows the block diagram of the bias circuitry. The BIAS ON key controls a relay in the 7200 that connects the bias source to the HI inputs. The BIAS output provides an attenuated monitoring signal proportional to the actual bias voltage with a ratio of 10mV/V

A digitizer or ADC in the test setup converts the analog output from the capacitance meter to digital data for further analysis. The market offers many types of instruments that fulfill these requirements, ranging from a simple PC data acquisition card to a Digital Storage Oscilloscope (DSO). Users will probably already own suitable equipment. Advantages of using a DSO are: more flexible triggering and synchronization capabilities, analog input scaling, measurement bandwidth control, averaging and a graphic display of the data.
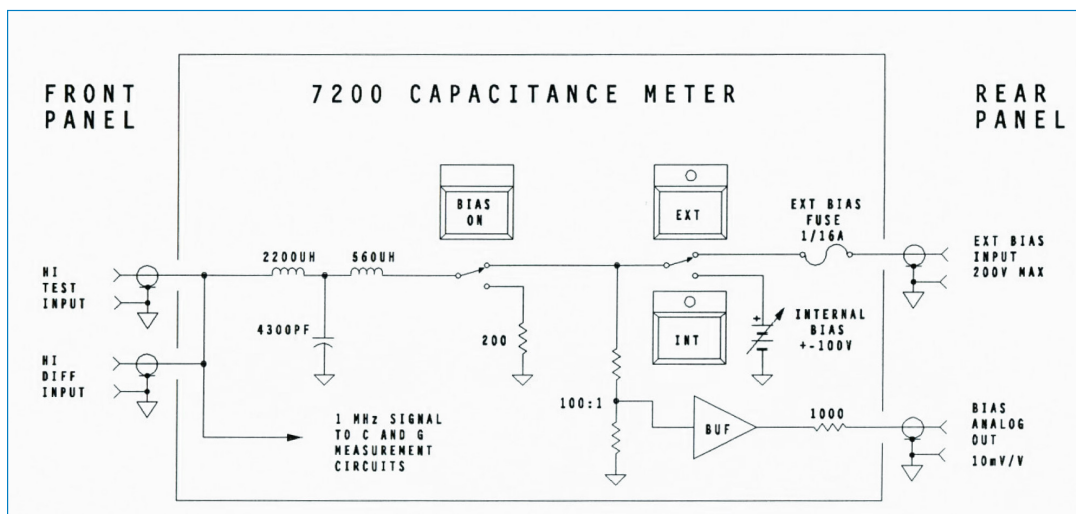

Figure 3. Block Diagram of Internal Bias Circuits

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The computer performs data analysis and measurement control. The measurement controller functionality of the computer, as a minimum, synchronizes the bias pulse with the data capture process. This can be done with a TTL trigger output or over an IEEE-488 interface. The interface also provides a way for the computer to control key parameters such as bias pulse width and amplitude, capacitance meter ranging and zeroing, etc.

Generating Pulse Bias

DLTS measurements require a pulse applied to the semiconductor device under test. For accurate measurements, the pulse must not overload or otherwise interfere with the measurement circuitry of the capacitance meter.

This application note describes three different methods of generating pulse bias: using the internal bias supply controlled via the IEEE-488 interface, using a pulse generator connected through the external bias input, and using a custom designed test fixture and a TTL compatible gate signal. The advantages and limitations of each method are presented. For purposes of illustration a 1N4003 diode was used as the test specimen. When pulse bias is applied, this diode type exhibits a voltage-variable capacitance that conveniently illustrates the response time and overload recovery of the Model 7200.
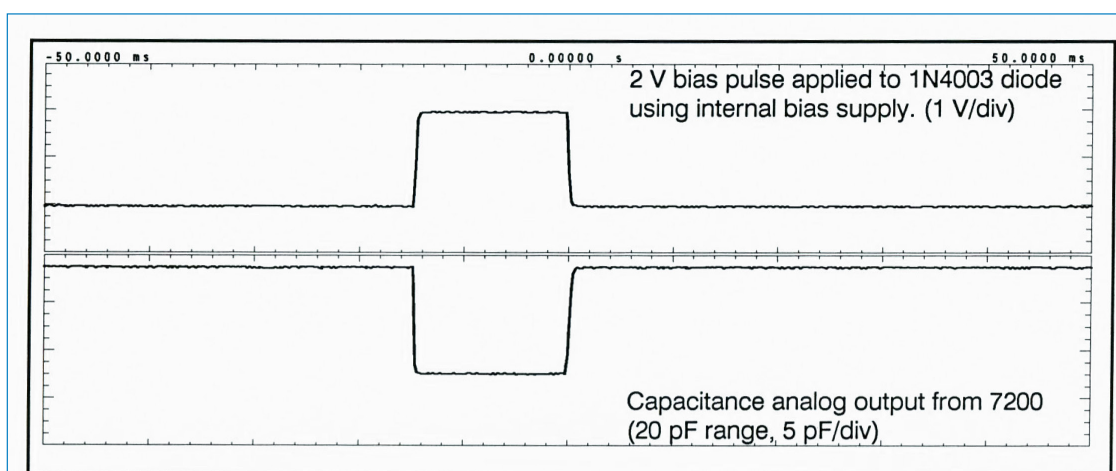

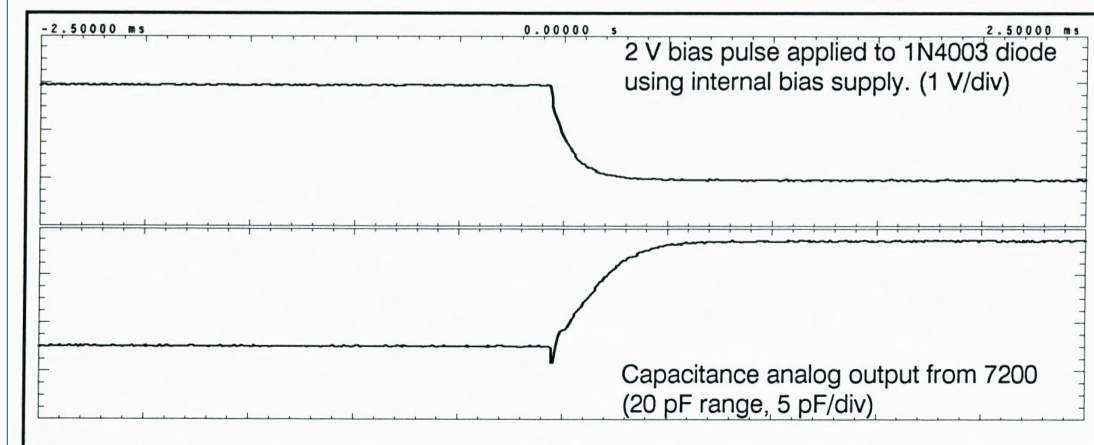
Figure 4. IEEE-488 Controlled Internal Bias Pulse

Figure 5. IEEE-488 Controlled Internal Bias Falltime

Pulse bias using the internal bias supply

This method of generating pulse bias uses the internal bias supply of the 7200. Commands over the IEEE-488 interface control the pulse amplitude and pulse width. The bias supply can be accurately adjusted over an amplitude range of ± 60 volts with 1 mV resolution below 20 volts, and 10 mV resolution from 20 to 60 volts. The pulse width is determined by software timing of the program and the syntax of the command string.

Programming examples in this application note only describe the data string that communicates with the 7200. The complete syntax to generate the IEEE-488 data transfer depends on the programming language and computer. Please refer to the 7200 Operation manual for detailed information on programming.

The first programming example generates a 15 ms pulse as shown in Figure 4. A sequence of three data string transfers from the computer is used to generate the pulse.

''BI 0 VO BO'' (set bias voltage to 0 volts and enable bias supply output)

''WT BI 2 VO'' (enable delayed execution mode and set bias amplitude to +2 volts)

''TR 0 VO IM'' (execute 2 volts followed by 0 volts and then restore the immediate mode)

The second programming example generates a pulse with a width of approximately 28 ms in a single data string transfer from the computer.

''BI 0 VO 2 VO 0 VO '' (set bias voltage to 0 volts, 2 volts and 0 volts)

The third programming example generates a pulse with a width of approximately 65 ms. Inserting an additional (BI) command adds approximately 27 ms of delay.

''BI 0 VO 2 VO BI 0 VO '' (set bias voltage to 0 volts, 2 volts and 0 volts)

The fourth programming example generates pulse widths that are hundreds of milliseconds long by creating a software delay between data transfers to the 7200.

''BI 0 VO BO '' (set bias voltage to 0 volts and enable bias supply output)

''BI 2 VO'' (set bias amplitude to + 2 volts)

< software delay in milliseconds >

''BI 0 VO'' (set bias amplitude to 0 volts)

There are several advantages of using the internal bias supply. An external pulse generator is not required, and since the supply is an integral part of the 7200, the instrument provides the connection between the bias voltage source and the device. Another advantage is that the bias pulse does not have to switch off to return to 0 volts, but can be a voltage step between two programmable voltages. For example, a small forward bias can be applied after the reverse bias pulse.

There are limitations associated with this method. Controlling the internal bias voltage via the interface limits the pulse width that can be

There are limitations associated with this method. Controlling the internal bias voltage via the interface limits the pulse width that can be generated. The minimum width over the full range is approximately 15 ms (Figure 4). The transition time for small voltage steps is approximately 200 us (Figure 5) but, unlike many pulse generators, is not adjustable. Also, it is more difficult to get precise timing between the bias pulse and the data capture. Hardware triggering in the digitizing device is recommended, so it can detect the bias pulse to synchronize the start of the data capture.
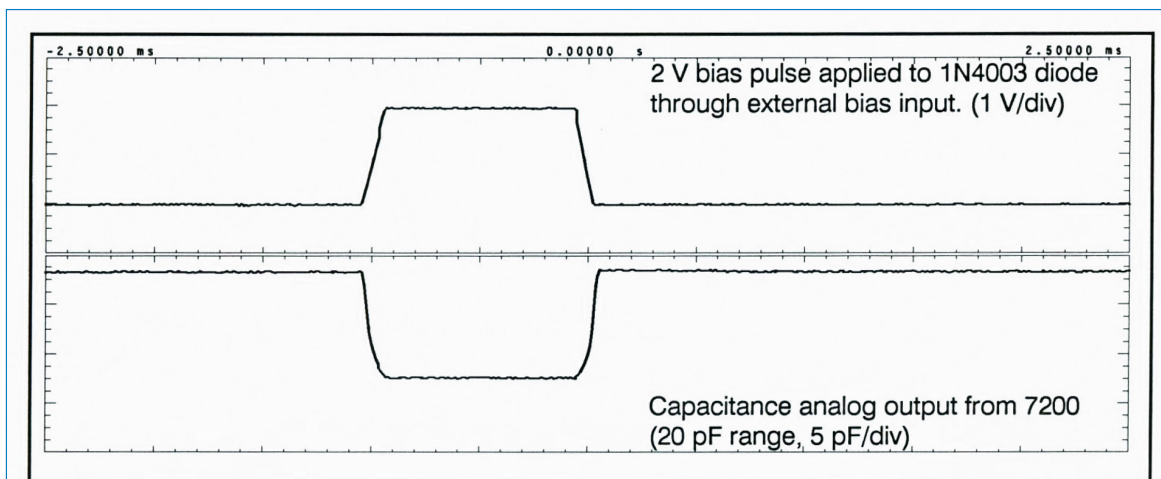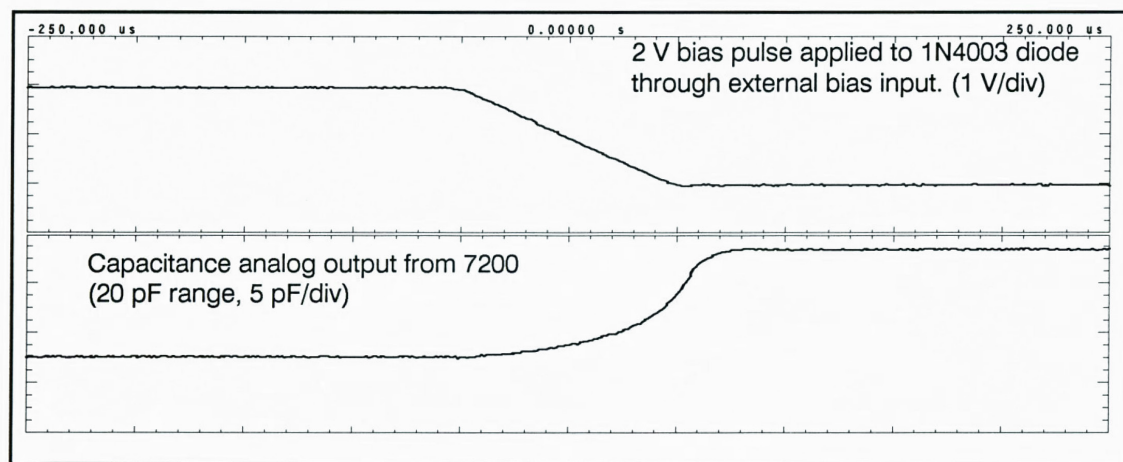

Figure 6. External Pulse Bias Response With Slow Edges

Figure 7. External Pulse Bias Falltime With Slow Edge

Pulse bias using a pulse generator
The second method for generating pulse bias uses a pulse generator connected through the rear panel external bias input of the 7200. The pulse generator controls the pulse amplitude and pulse width. The external bias input provides a convenient method of connecting the pulse to the test specimen, and the voltage can be measured and displayed by the 7200. Pulse amplitudes up to ±60 volts and pulse transitions as fast as 20 V/ms can be applied through the rear panel input without overloading the measurement circuits of the 7200. Figures 6 and 7 show the effects of applying a 2 volt pulse through the external bias input. The pulse width is approximately 1 ms and the transition time is 100 us.

There are several advantages of using a pulse generator as the pulse bias source. The pulse width can be as fast as 200 us for small pulse amplitudes. Also, synchronization with the data capture device is easier since most pulse generators have a trigger input and output capability.
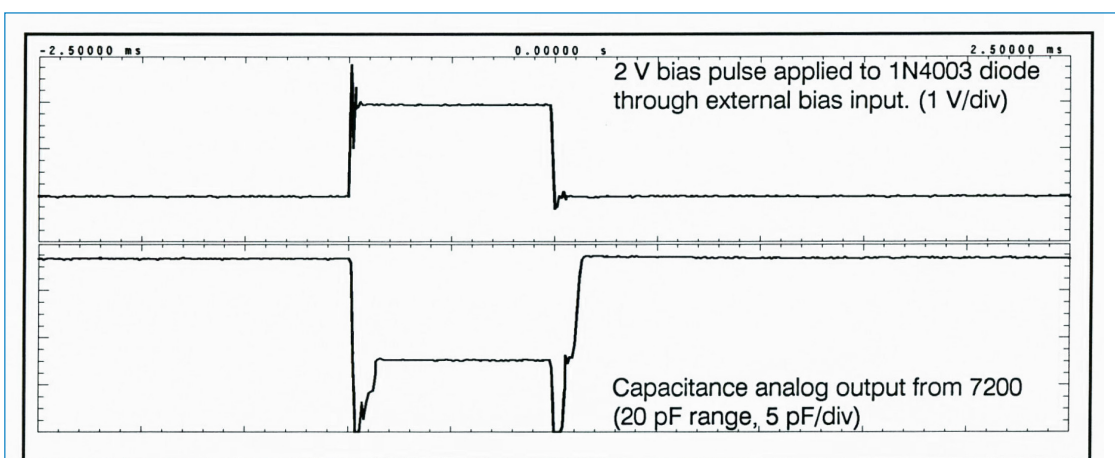
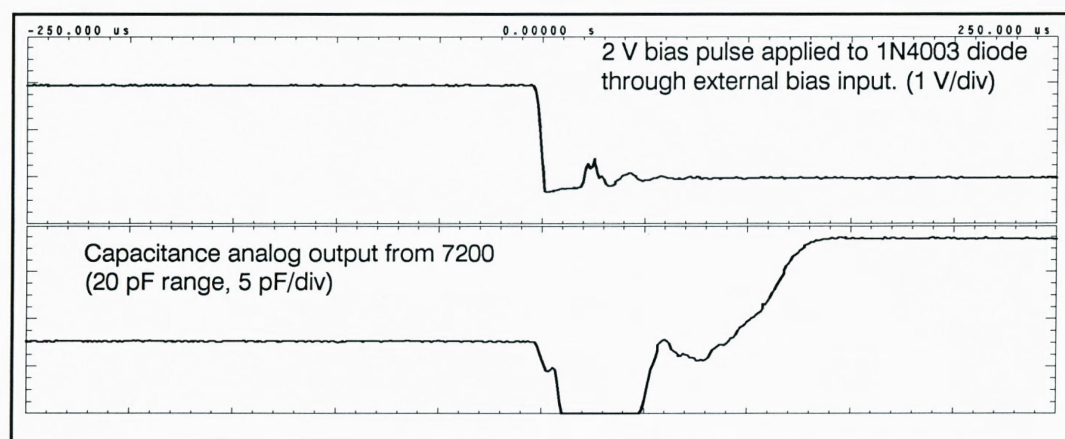**Figure 8. External Pulse Bias Response With Fast Edges**

Top trace: 2 V bias pulse applied to 1N4003 diode through external bias input. (1 V/div)

Bottom trace: Capacitance analog output from 7200 (20 pF range, 5 pF/div)

Time axis: -2.50000 ms, 0.00000 s, 2.50000 ms

Figure 9. External Pulse Bias Falltime With Fast Edge

Top trace: 2 V bias pulse applied to 1N4003 diode through external bias input. (1 V/div)

Bottom trace: Capacitance analog output from 7200 (20 pF range, 5 pF/div)

Time axis: -250.000 us, 0.00000 s, 250.000 us

The primary limitation of this method is that the slew rate of the bias pulse must be limited to less than 20 V/ms. Figures 8 and 9 illustrate the results of a high-speed pulse applied through the external bias input. The pulse has overshoot and ringing that momentarily overdrives the capacitance measurement circuits.

Pulse bias using custom DLTS test fixture
The third method for generating pulse bias uses a custom-designed test fixture to apply bias pulses across the test specimen in a differential way. The schematic and parts list of the test fixture are shown in Figure 10. Unlike the two previous methods that apply pulsed bias to the HI input of the meter, this method maintains a constant bias voltage at the HI input and generates the pulsed voltage at the LOW side of the DUT. This technique can produce faster transition times because the test device isolates the measurement circuit from bias pulse transitions.

The DC equivalent diagram in Figure 11 illustrates the differential bias method. When pin 1 of the analog switch connects to ground through pin 8, the bias voltage appears across the DUT. The differential voltage across the DUT drops to 0 volts when pin 1 of the analog switch connects to the bias supply through pin 2. The AC equivalent circuit (Figure 12) shows that C4 and C5 appear in series with the test device. The value of C4 should therefore be large compared to the capacitance of the test specimen, otherwise the measurement accuracy of the meter will be degraded.

Figure 13 shows the typical transition time of the capacitance analog output. A TTL compatible gate signal from a pulse generator or computer controls the pulse width. The test fixture can generate pulse widths of 50us or greater. The values of R1 and C4 determine the transition time, and increasing the value of R1 will make the transition time slower. With the values shown in Figure 10, the transition time is 25us. The bias pulse amplitude is controlled by setting the voltage of the internal bias supply. Although the internal bias voltage is settable to ±60 volts, voltages greater than ±15 volts will damage the analog switch and must be avoided.
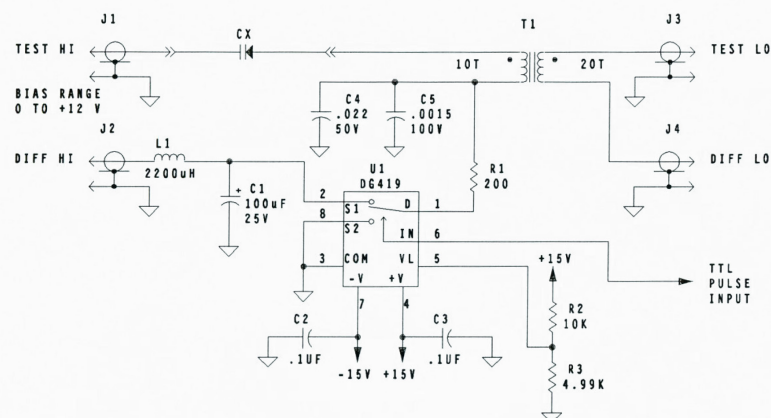
| Device	BEC Part #	Description
C1	283334000	100 μF, 25 V, Electrolytic
C2, C3	224268000	0.1 μF, 50 V, Ceramic
C4	224302000	0.022 μF, 50 V, Ceramic
C5	20013100A	1500 pF, 100 V, Mica
L1	400141000	2200 μH
R1	341229000	200 ohm, 1%, 1/4 watt
R2	341400000	10 K, 1%, 1/4 watt
R3	341367000	4.99 K, 1%, 1/4 watt
U1	53452400A	DG419 analog switch
T1	805035000	toroid core
J1-J4	477288000	BNC push-on jacks

Figure 10. External Pulse Bias Circuit
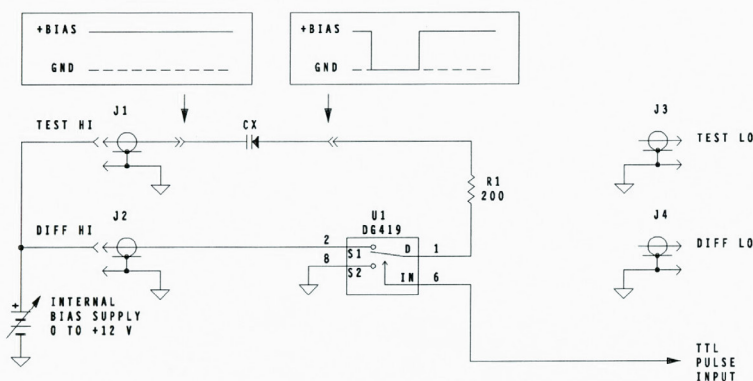
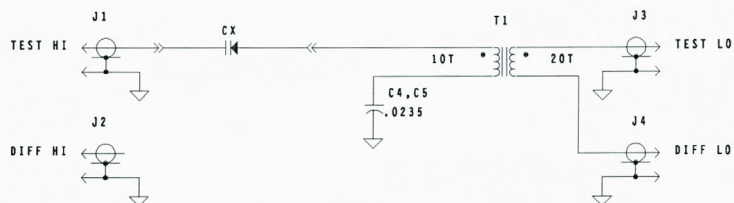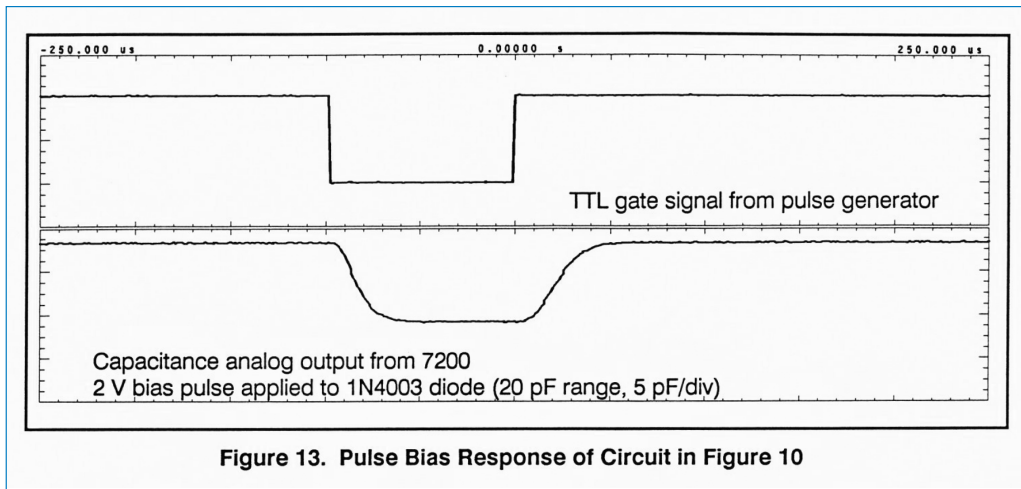Figure 11. DC Equivalent of External Pulse Bias Circuit

Figure 12. AC Equivalent of External Pulse Bias Circuit

-250.000 us   0.00000 s   250.000 us

TTL gate signal from pulse generator

Capacitance analog output from 7200
2 V bias pulse applied to 1N4003 diode (20 pF range, 5 pF/div)

Figure 13. Pulse Bias Response of Circuit in Figure 10

The advantages of this method are: the capacitance measurement is not overloaded by fast pulse transitions; the test fixture is simple to assemble and customize; and the internal bias supply voltage determines pulse amplitude. The disadvantage is that the pulse amplitude is limited to the ± 15 volt operating range of the analog switch.

Conclusion

The Model 7200 is an ideal capacitance meter for measuring Deep Level Transient Spectroscopy. The fast response time of the analog output provides an accurate reference voltage proportional to the capacitance. For more information about the material in this application note, or about the Model 7200 Capacitance Meter, please contact our local Application Engineers or the factory. See information on back cover.

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