BOONTON

Application Note IM-001

Using the Model 7200 Capacitance Meter for DLTS Measurements

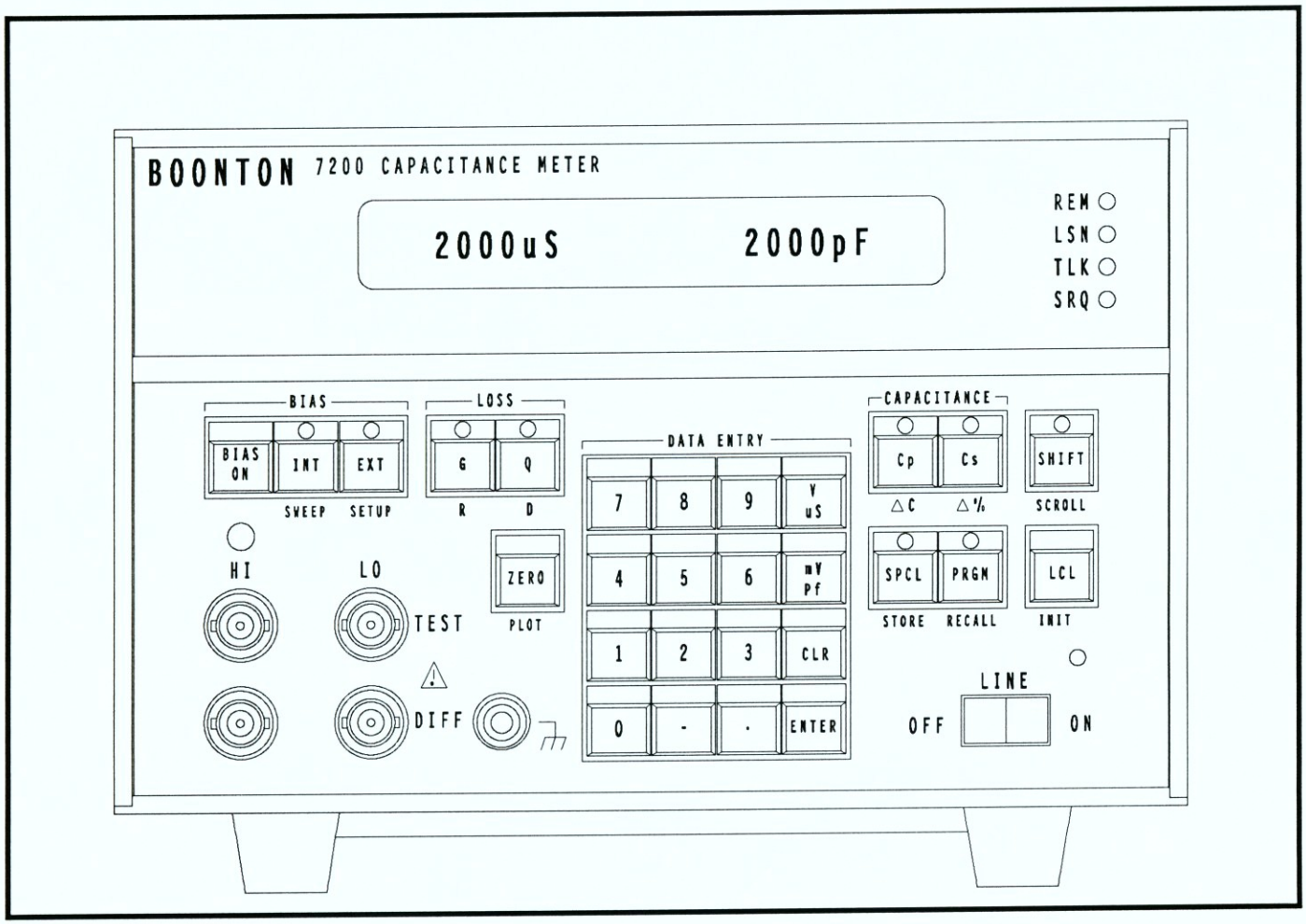
Introduction

The Boonton Model 7200 is a precision, high-speed capacitance meter 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 contains guidelines for using the Model 7200 in a DLTS system, analyzes several ways of generating pulse bias, and presents examples of the measurement capabilities of the Model 7200.

The DLTS Measurement

DLTS involves analysis of junction capacitance vs. time following a bias pulse. There are four basic devices in a DLTS measurement system: bias supply, capacitance meter, digitizing converter, and computer. See Figure 1.

The first device is the bias supply, which must provide a bias voltage across the test specimen that is adjustable in amplitude and duration. Control of the pulse transition time (risetime and falltime) is also desirable. The range of bias voltage and pulse period varies by application. Often, the bias



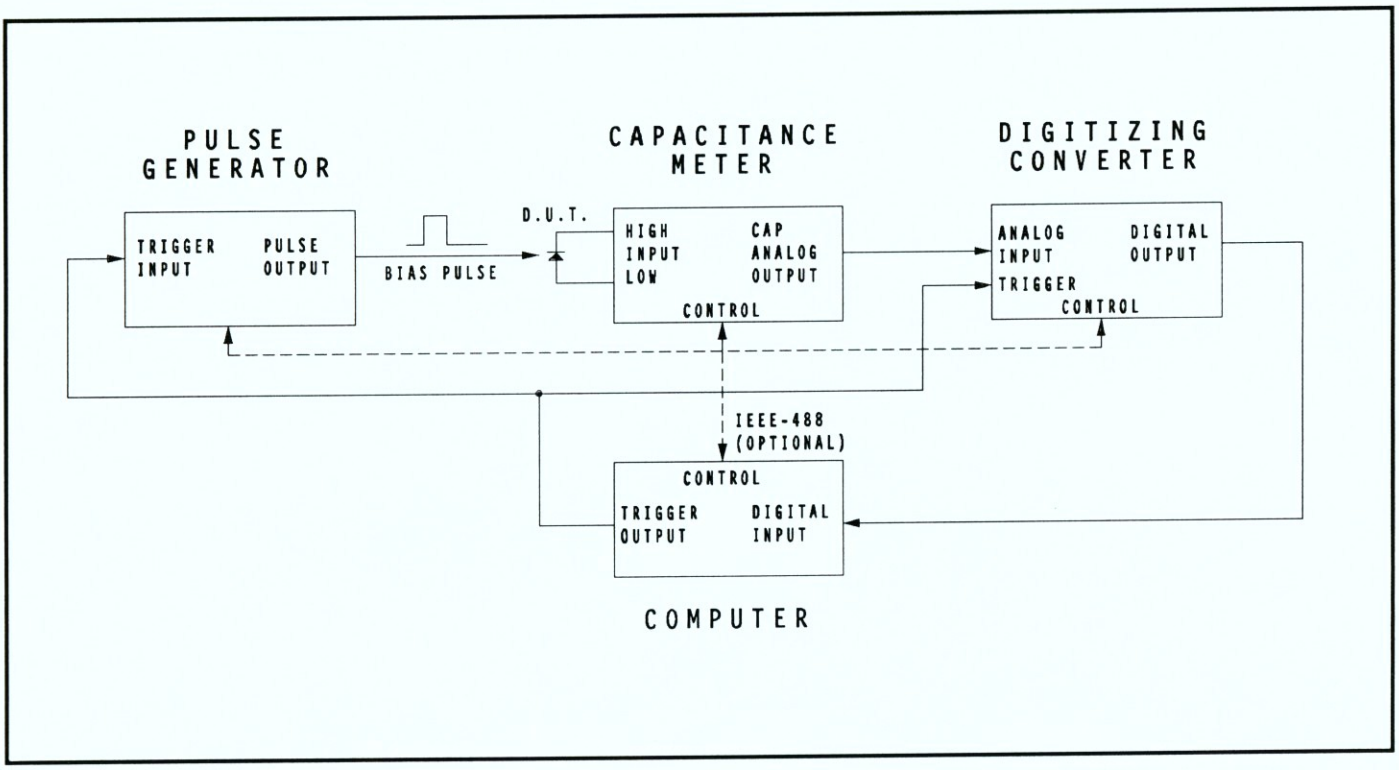


Figure 1. Typical DLTS Measurement System

voltages are as low as 2 volts and pulse periods are greater than 50 μs. An example of a suitable, commercially available device is the HP8012B Pulse Generator.

The second device is the capacitance meter. The key feature here is the analog output that presents a calibrated, real-time output voltage proportional to the specimen capacitance. In the past, many DLTS systems have been designed around the Boonton Model 72BD. An optional version of the 72BD includes several hardware modifications that improve the meter's response time, overload recovery and signal-to-noise ratio. The next generation capacitance meter from Boonton, the Model 7200, includes these enhancements in a modern, microprocessor controlled product that is easy to use and maintain. Figure 2 shows the block diagram of the measurement circuits of the Model 7200.

The 7200 uses a wideband amplifier with high-speed clamping circuitry that provides faster overload recovery than the tuned, 1 MHz amplifier in the 72BD. Improved shielding in the measurement circuitry reduces noise and digital interference at the analog output and the transition time is typically less than 25 μs.

The test and differential connections are essentially the same as those of the 72BD. The 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 installing a compensating capacitor on the differential terminals or by zeroing the measurement using the ZERO key. Capacitance of up to ±2000

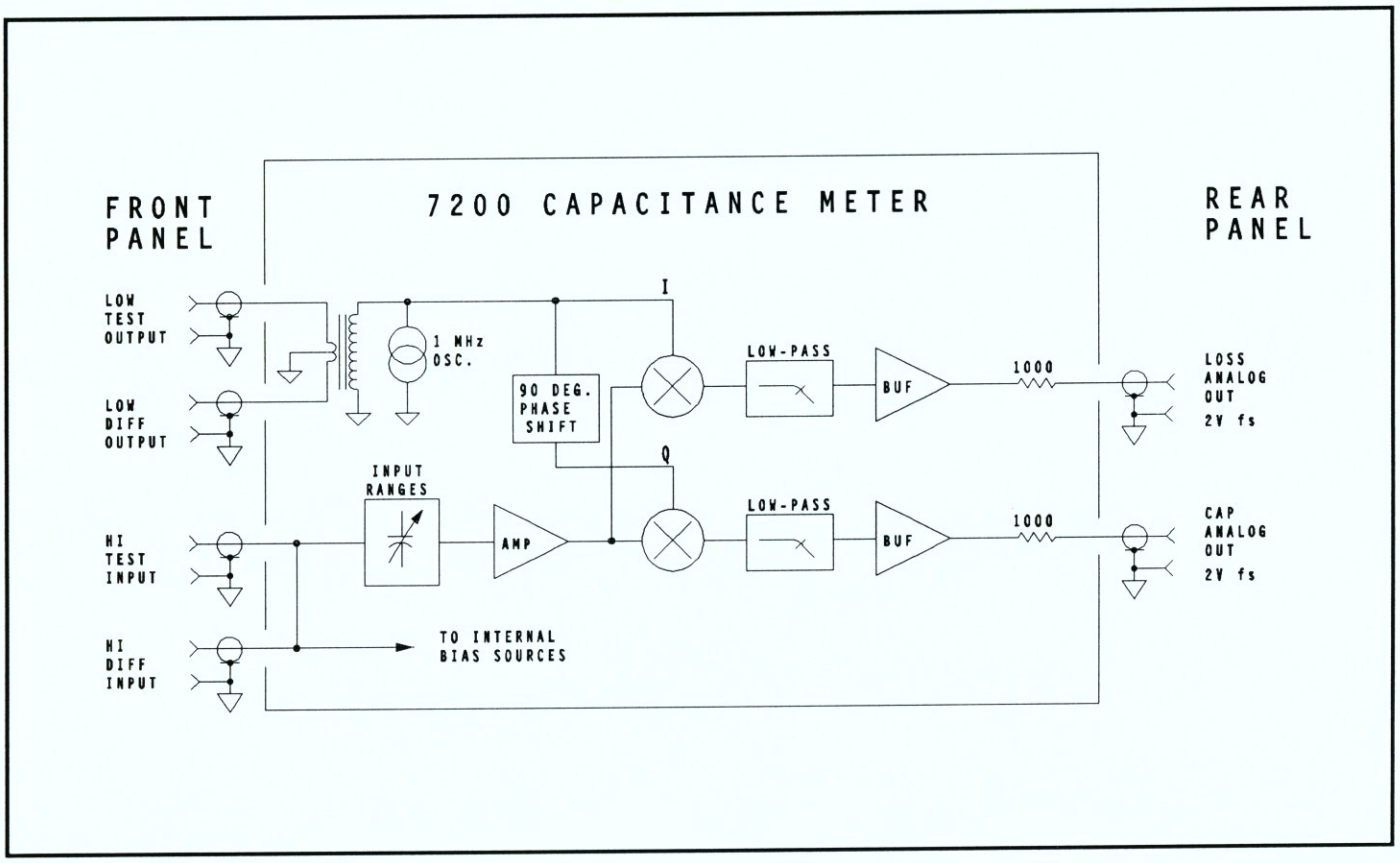


Figure 2. Block Diagram of Measurement Circuits

pF can be zeroed with a single keystroke. Adding a compensating capacitor on the differential terminals allows the instrument to operate on a more sensitive capacitance range.

The Model 7200 has two additional features that greatly simplify a DLTS measurement system: programmable internal bias supply and the external bias measurement function. The internal bias supply voltage range is ±100 volts and is settable from the front panel or over the IEEE-488 interface bus. Externally applied bias voltages are measured and displayed by the 7200 eliminating the need for a 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. An attenuated form of the bias voltage (10mV/V) is available for monitoring purposes at the BIAS analog output connector on the rear panel of the 7200.

The third device is a digitizer or A/D converter, which converts the analog output from the capacitance meter to digital data for the computer to process. The data conversion rate and resolution are the essential specifications of the digitizing device. The simple approach is to install a data acquisition card containing a 12-bit, 25 μs A/D converter in a personal computer. A more exotic (and expensive) approach is to use a digital storage oscilloscope (DSO) as the digitizer. The HP54503A Digitizing Oscilloscope was used to capture the waveforms in this application note. The advantages of using

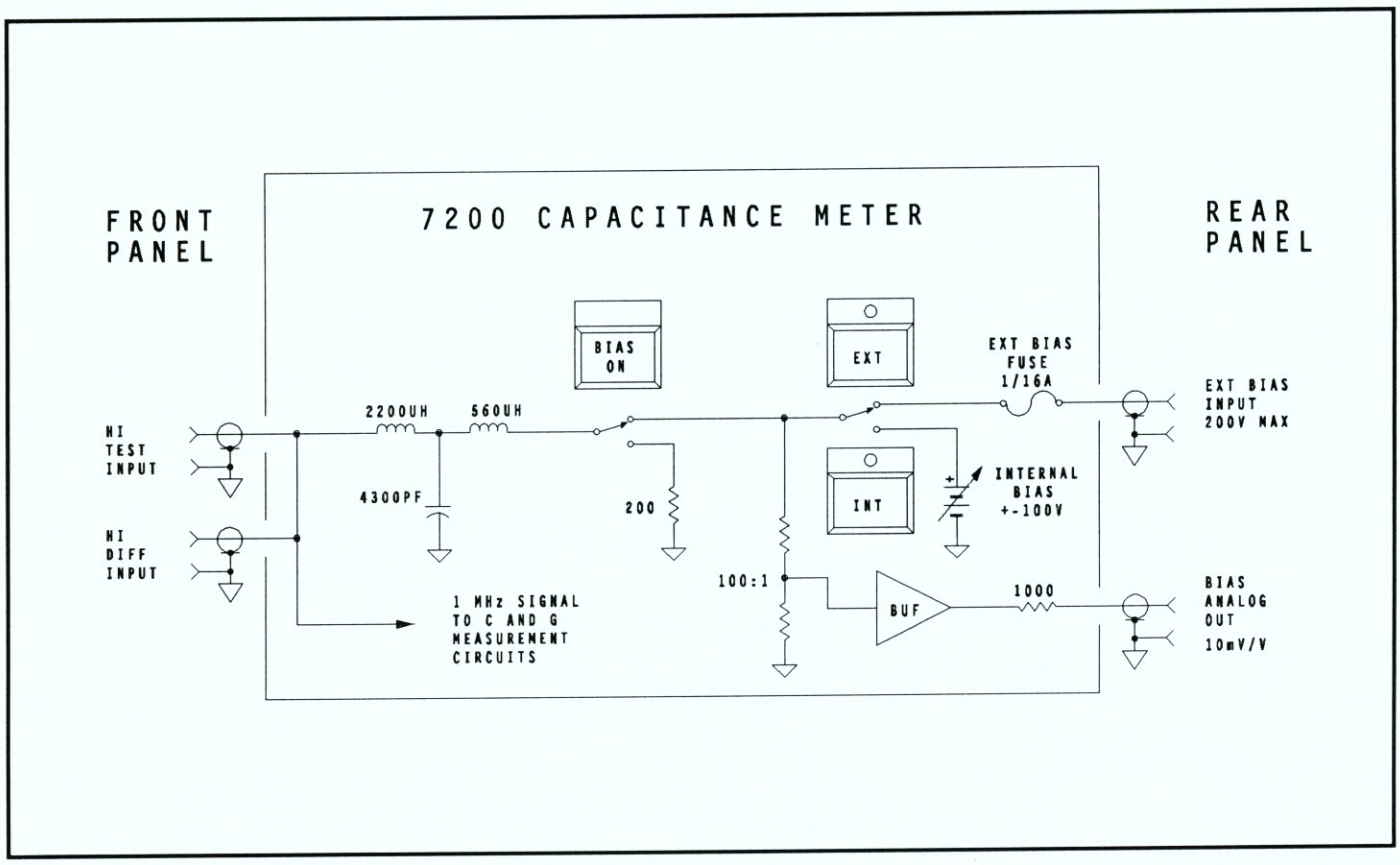


Figure 3. Block Diagram of Internal Bias Circuits

a DSO are: more flexible triggering and synchronization capability, analog input scaling, measurement bandwidth control, averaging, and a graphic display of the data.

The fourth device is a computer, which primarily performs data analysis and measurement control. The extent of the computation performed on the data is application dependant, but generally, the computer processes the raw data from the digitizer and generates graphic and tabular output in the desired format. 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. Many measurement instruments, including the Model 7200, are equipped with 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

The key to successful DLTS measurements lies in the pulse bias generator. The bias pulse must be applied to the test specimen in a way that will 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

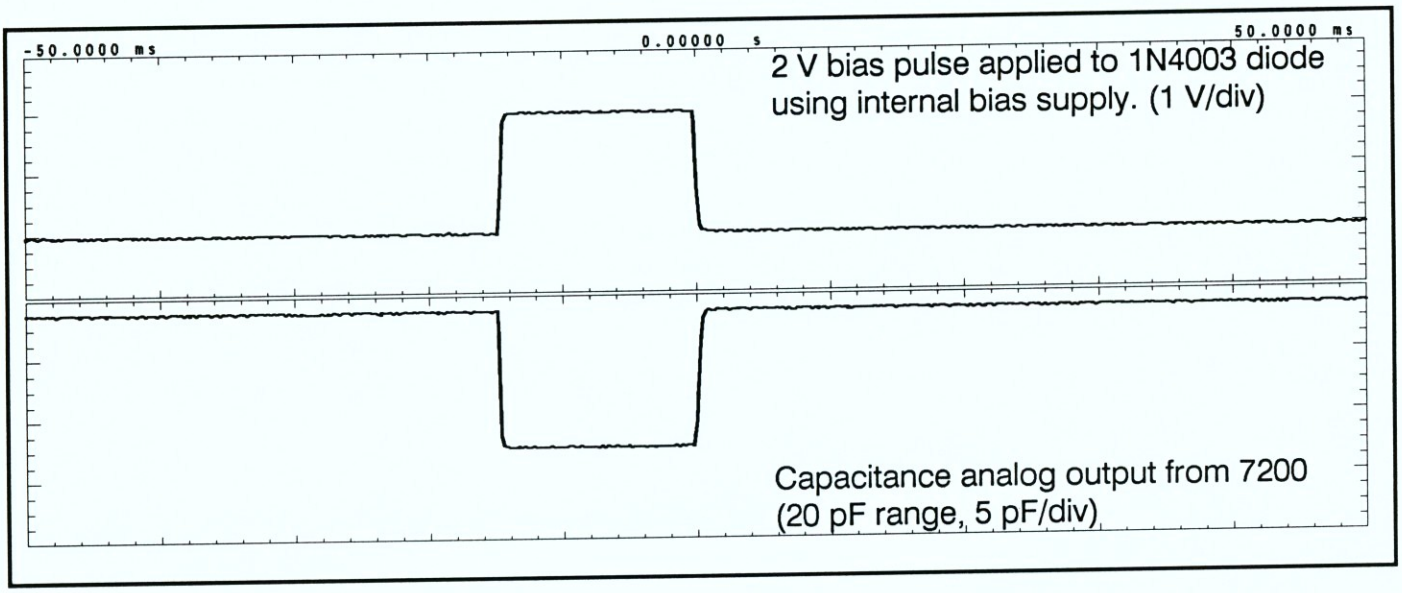


Figure 4. IEEE-488 Controlled Internal Bias Pulse

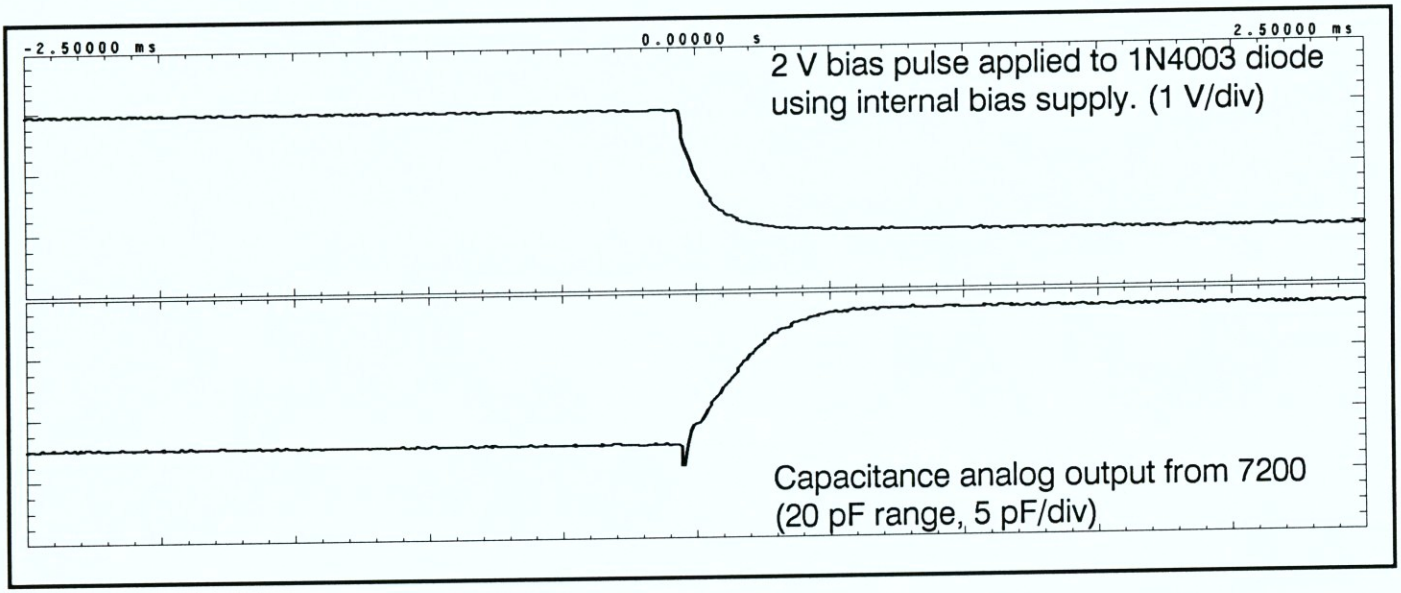


Figure 5. IEEE-488 Controlled Internal Bias Falltime

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.

Pulse Bias Using The Internal Bias Supply

The first method for 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 ±100 volts with 1 mV resolution below 20 volts and 10 mV

resolution from 20 to 100 volts. The pulse width is determined by software timing delays in the computer program and the syntax of the command string.

The 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. For more information, the Operation section of the 7200 manual lists all the bus programming commands and data format rules.

The first programming example can generate the 15 ms pulse width shown in Figure 4. A sequence of three data string transfers from the computer is used to generate the bias 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 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 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 to using the internal bias supply. The internal bias supply replaces the pulse generator, 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 0 volts. The bias pulse 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, however, limitations associated with this method. Controlling the internal bias voltage via the interface limits the minimum pulse width that can be generated to approximately 15 ms (Figure 4). The transition time for small voltage steps is approximately 200 μs (Figure 5) and, 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 that can detect the bias pulse may be needed to synchronize the start of the data capture.

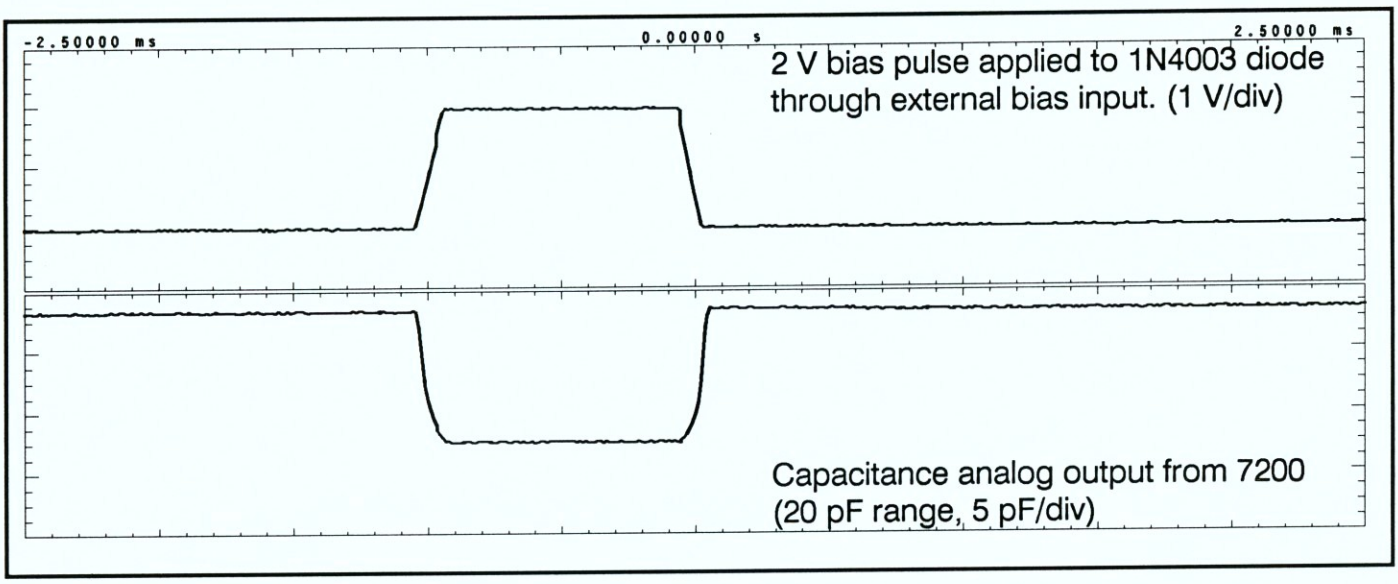


Figure 6. External Pulse Bias Response With Slow Edges

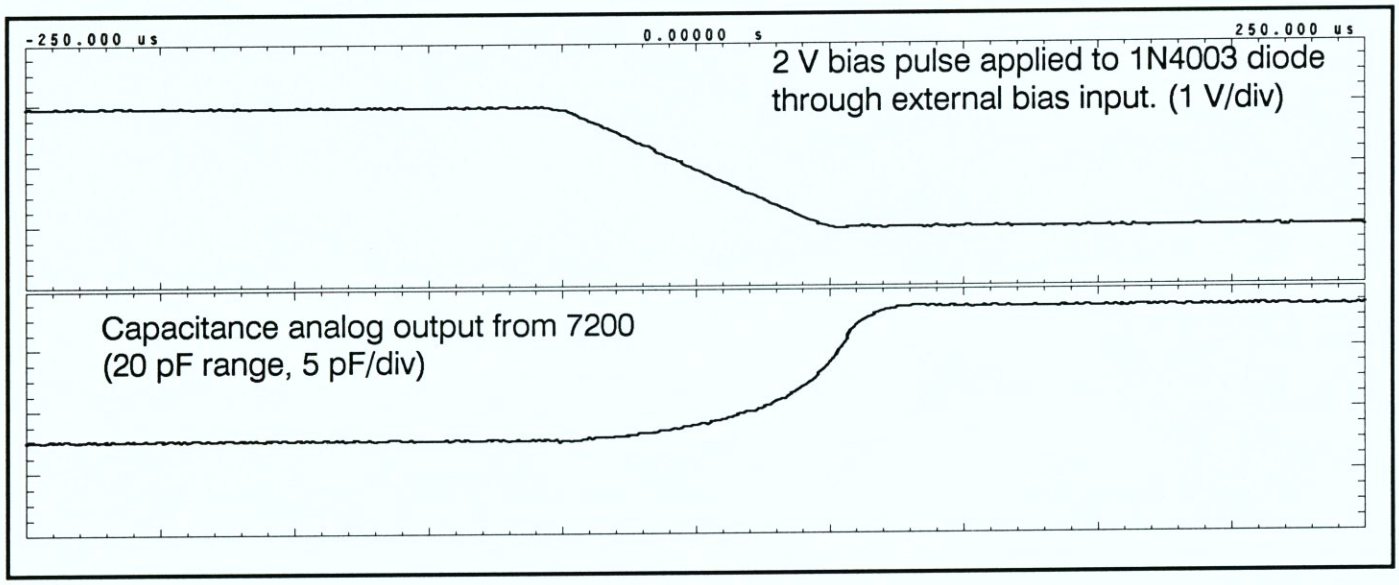


Figure 7. External Pulse Bias Falltime With Slow Edge

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 ±200 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 μs.

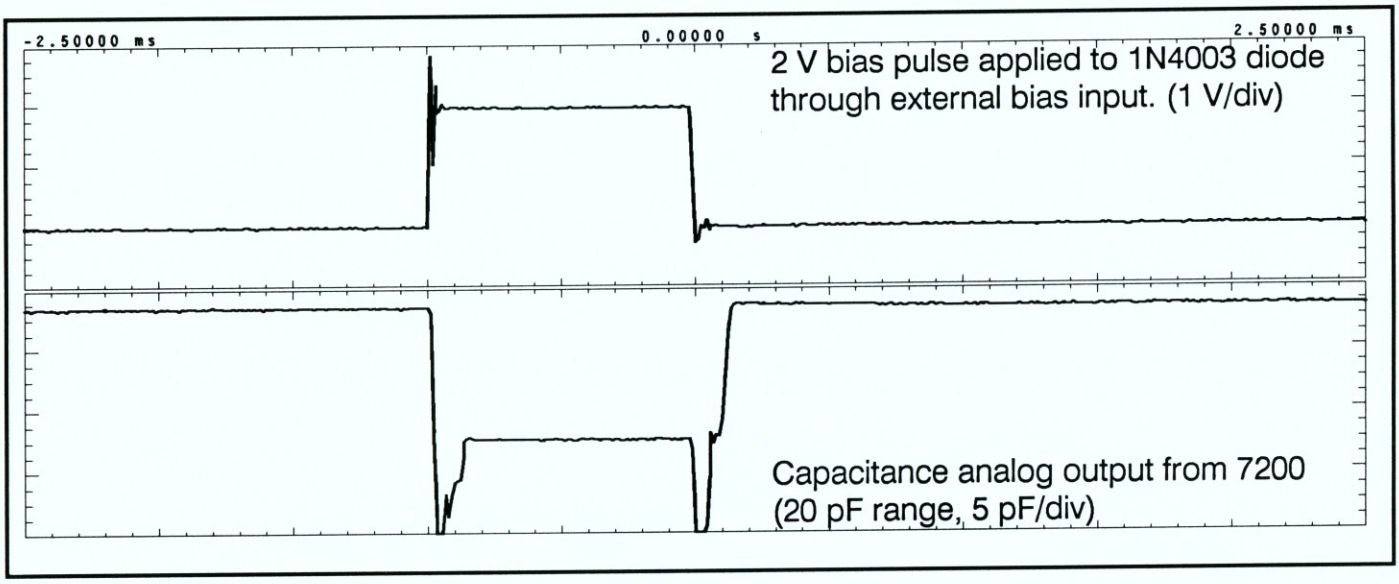


Figure 8. External Pulse Bias Response With Fast Edges

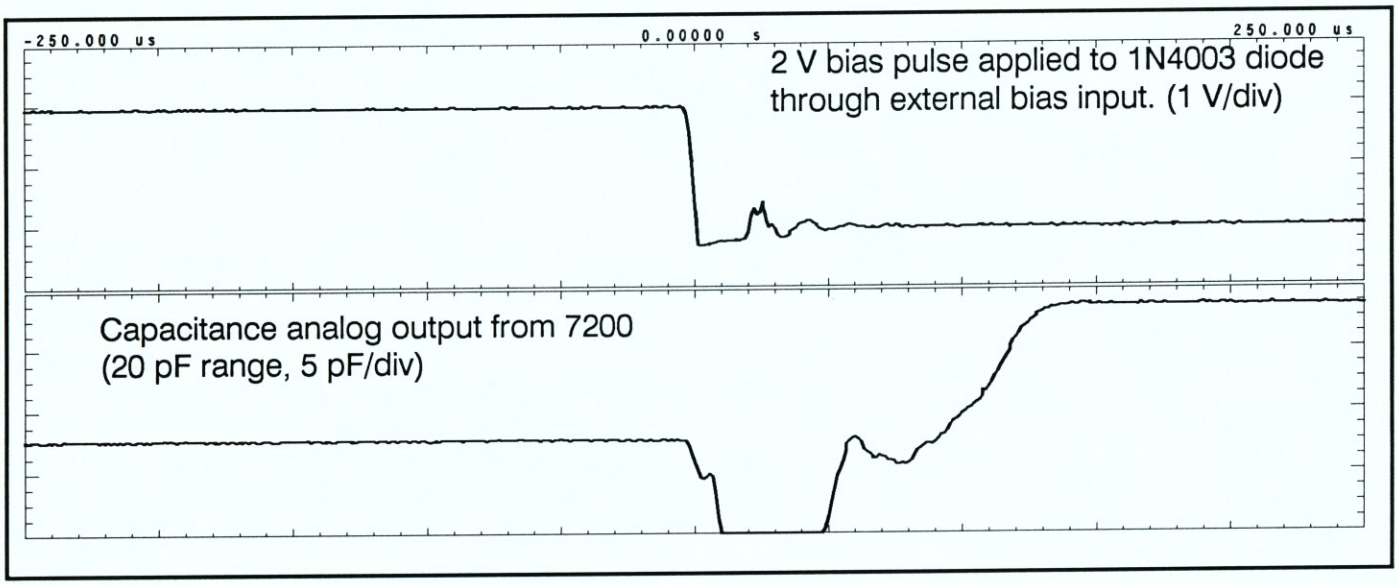


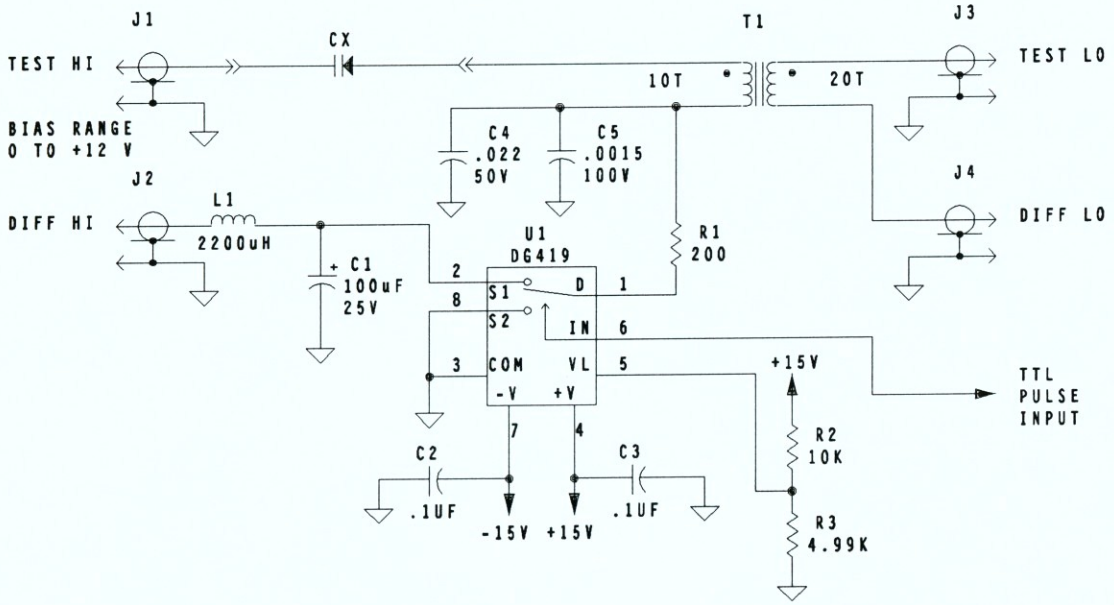
Figure 9. External Pulse Bias Falltime With Fast Edge

There are several advantages to using a pulse generator as the pulse bias source. The pulse width can be as fast as 200 μs for small pulse amplitudes. Also, synchronization with the data capture device is less complicated since most pulse generators have trigger input and output capability.

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 overdrive the capacitance measurement circuits.

Pulse Bias Using A 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 fashion. 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 test specimen. This technique can produce faster transition times because the test device isolates the measurement circuits from bias pulse transitions.



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

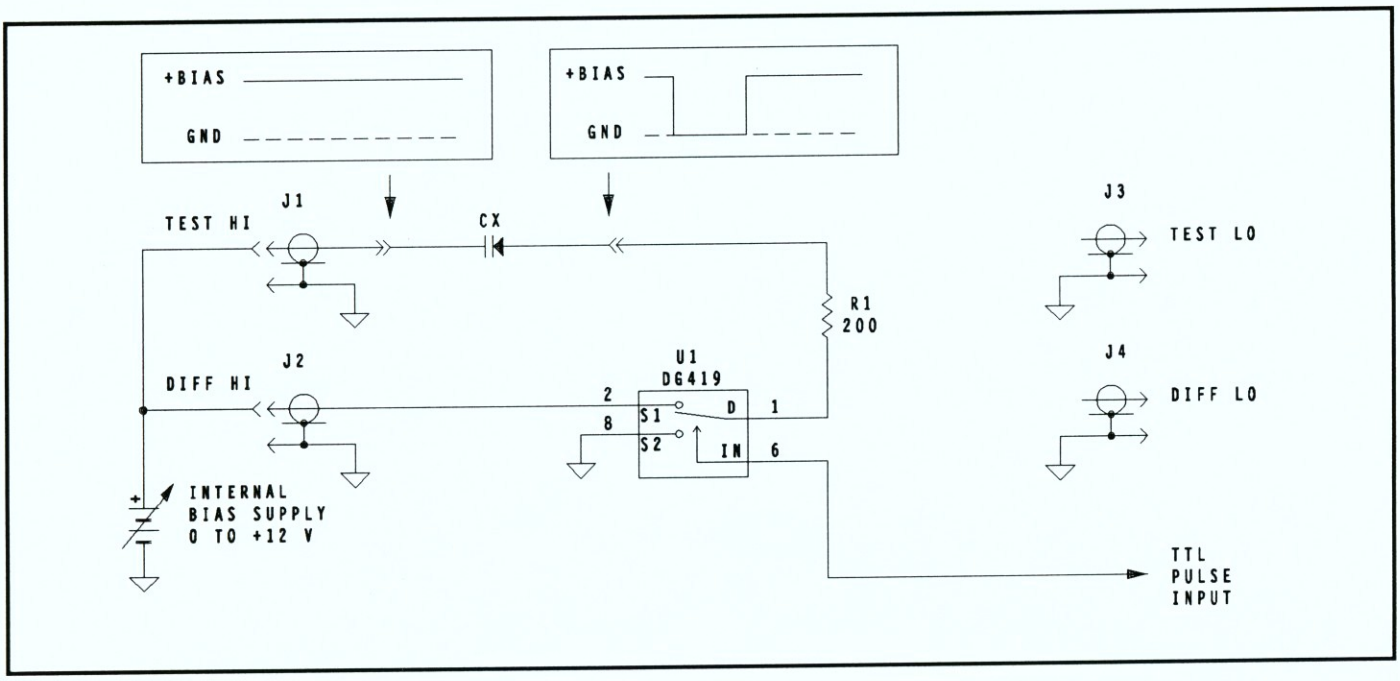


Figure 11. DC Equivalent of External Pulse Bias Circuit

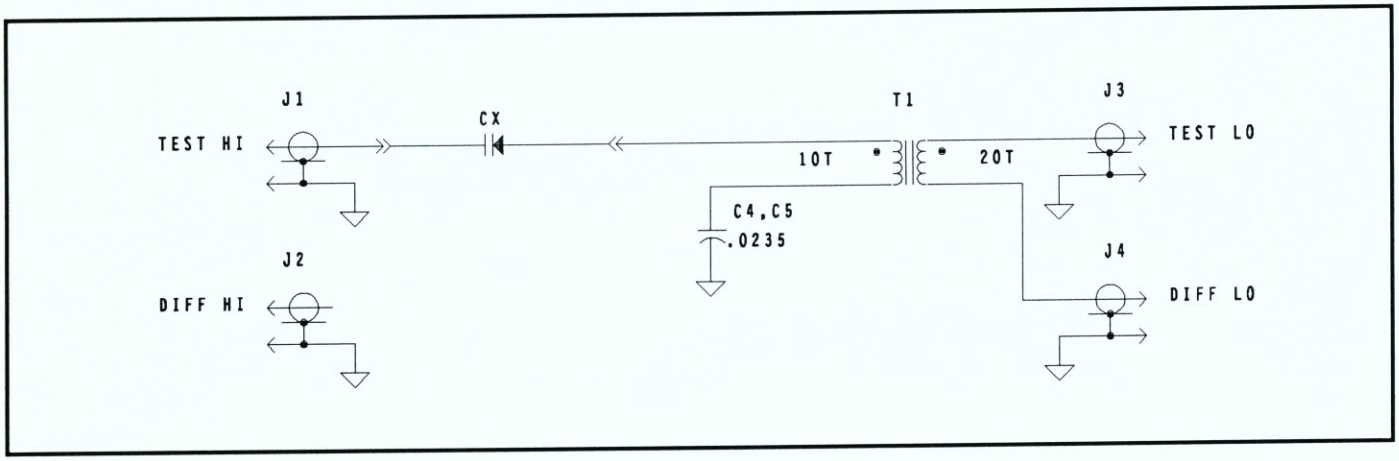


Figure 12. AC Equivalent of External Pulse Bias Circuit

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 test specimen. The differential voltage across the test specimen 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.

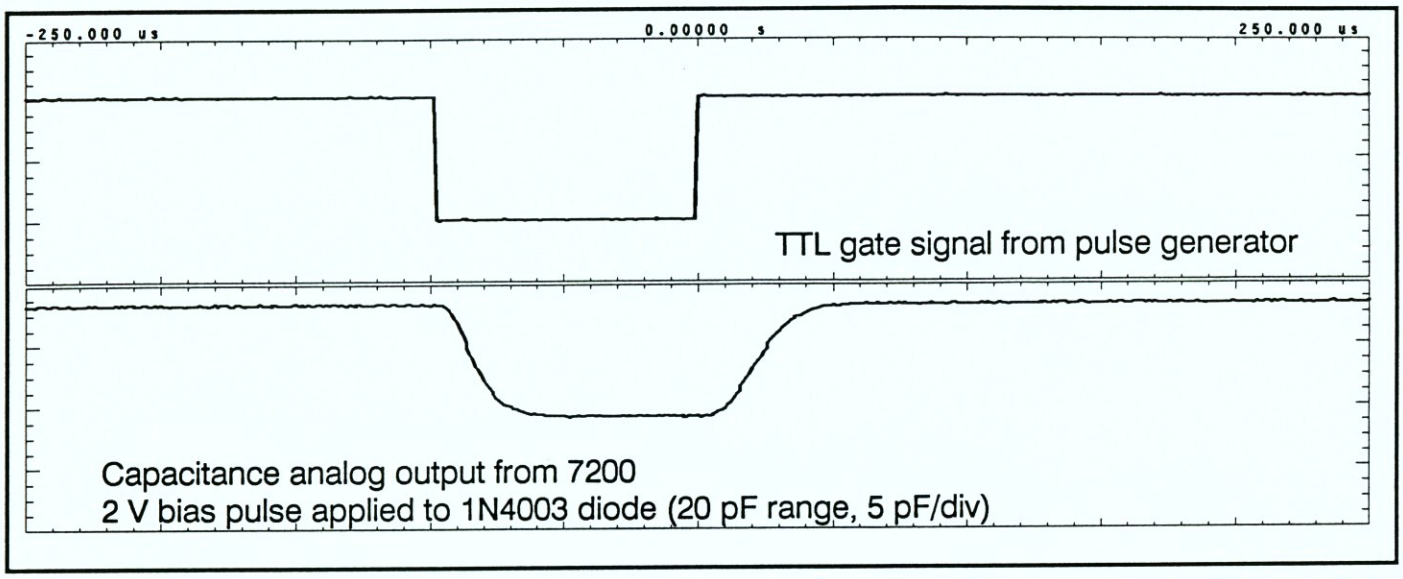


Figure 13. Pulse Bias Response of Circuit in Figure 10

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 and the test fixture can generate pulse widths of 50 μs 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 25 μs. The bias pulse amplitude is controlled by setting the voltage of the internal bias supply. Although the internal bias voltage is settable to ±100 volts, voltages greater than ±15 volts will damage the analog switch and must be avoided.

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 of this method 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 measurement circuits are less susceptible to overload than the 72BD and the fast response time of the analog output is a standard feature of the 7200. For more information about the material in this application note or about the Model 7200 Capacitance Meter contact the Applications Department at the address below:

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