MODEL 685 SERIES
AWG'S FOR OPTICS, PHOTONICS AND LASERS

APPLICATION NOTE

Introduction

Nowadays applications based on optics, photonics, and lasers are becoming extremely popular. The newest generation of scientists are opening new territories for their applications, like lidar for automotive, medical solutions, aerospace & defense, quantum and laser sensors.

The testing challenges, time-to-market tasks and the increasingly demanding applications makes our state of the art arbitrary waveform and function generator, as the right choice to face these challenges, providing a flexibility that has never seen before. Features of the Model 685 gives engineers a powerful instrument to produce all type of pulses, signals and modulations.

Various applications require different type of signals, here below we report some AWG application examples:

- Generation of high amplitude and high-speed pulses to directly drive the electro-optic modulators.
- Generation of different kinds of signals and pulses to make stimuli for quantum optics applications.
- Generation of pulses to drive the pulsed laser diodes.

Key Issues:
- Generate pulses for optics, photonics and laser applications.

Solutions:
- Model 685 Series AWG's for Optics, Photonics and Lasers

Results:
- Accelerate testing, reliability, characterization of optics & photonics systems.
- Reduce the time to generate pulses and control signals for lasers and electro-optic modulators.

Electro-optic Modulators

Integrated-optical waveguides can guide light along a determined path; analog to optical fiber. The waveguide consists of a channel with a higher refractive index compared to the surrounding material.

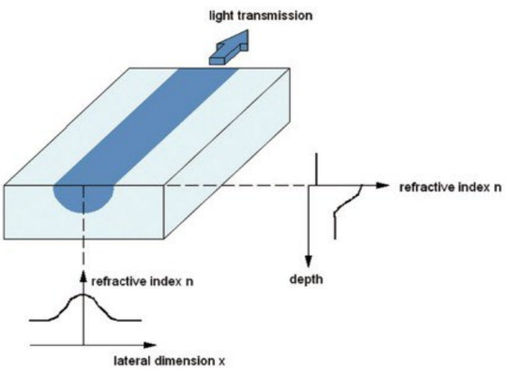


Figure 1: Integrated optical waveguide

The light is guided by means of total internal reflection at the channel walls. Depending on the wavelength, substrate refractive index, refractive index difference, width and depth of the channel, one or more transverse oscillation modes can be excited.
The single-mode operation is optimal since it is essential for the function of many integrated- optical elements. Integrated-optical elements are usually provided with optical fibers particularly in optical communication technology.

The linear electro-optic effect, also known as Pockels-Effect, is a second order non-linear effect consisting in the change of the refractive index of an optical material if an external electric field is applied. The amount of change in refractive index is proportional to the electric field strength, its direction and the polarization of the light.

The preferred material for the fabrication of integrated-optical modulators is Lithium niobate ($LiNbO_3$).

If an electric field is applied to a waveguide using electrodes of the length (L), the refractive index changes in the area between the electrodes, giving a phase shift of the guided light. The phase shift is linear to the applied voltage.

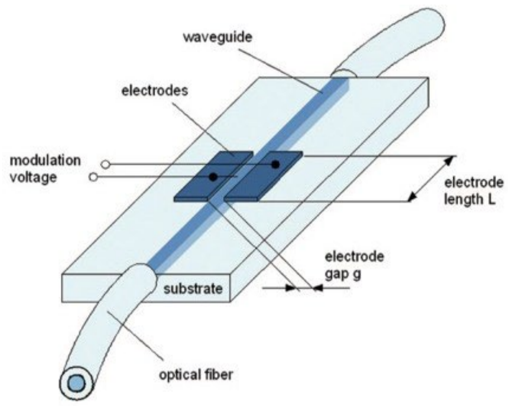


Figure 2: Phase Modulator

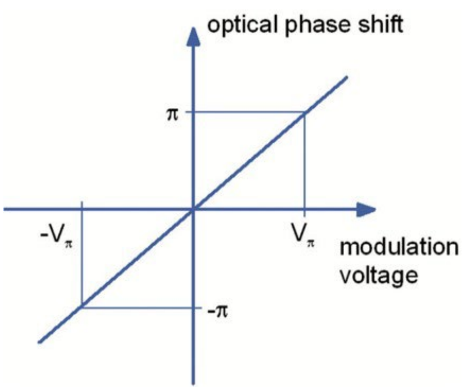


Figure 3: Phase Shift

This typically amounts to a few volts. For longer wavelengths, it is higher than for shorter ones at a given electrode geometry. For example, it can be expected to be **3 V** in the red (635 nm) and **10 V** in the telecommunication wavelength range (about 1550 nm).

Due to the very fast electro-optic response, the low control voltages, and the use of sophisticated electrode geometry, it is possible to achieve modulation at frequencies in the gigahertz range.

A phase modulator is inserted into an integrated Mach-Zehnder interferometer to form an amplitude modulator.

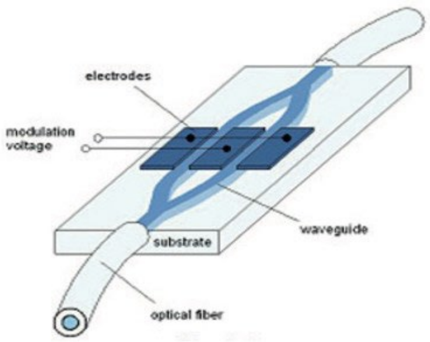


Figure 4: Mach-Zehnder amplitude modulator

Applying a voltage leads to a relative phase difference between the branches, which causes a change of the output power at the device, output by means of interference. So the device transmission can be controlled between a minimum and a maximum value (P min to Pmax).

A relative phase difference of π is needed for switching from on to off state or vice versa. The needed voltage is called the half wave voltage Vπ of the amplitude modulator.

Due to the push-pull operation, the half wave voltage of an amplitude modulator is the half of that of a phase modulator with equal electrode length. For example, it can be expected to be 1.5 V in the red at 635 nm and 5 V in the telecommunication wavelength range about 1550 nm.

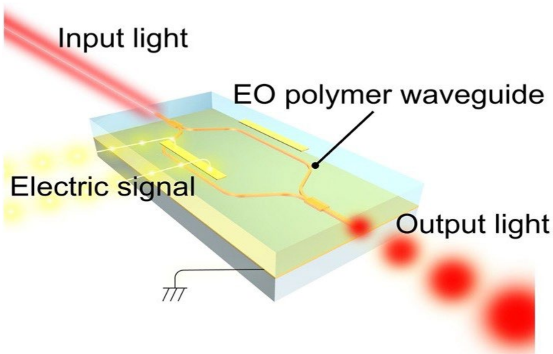


Figure 5: Input / Output light

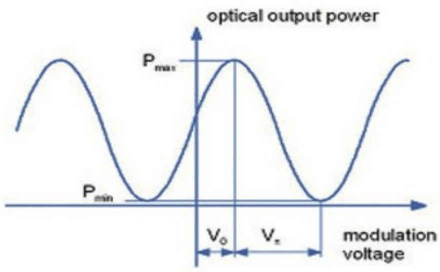


Figure 6: Amplitude modulator characteristic curve

Applying an RF signal as modulation voltage to the electrodes, this electrical input is translated into amplitude information.

The amplitude output depends on the voltage magnitude and shape, thus related to the position of the modulators operation point. The figure depicts the transmission of a binary pulsed electrical input into a binary optical output signal. If the voltage levels are notcorrect, that means the voltage is too high, or the offset is not correct. The modulator will react with non-correct optical output levels in binary operation or with higher harmonics in analog operation.

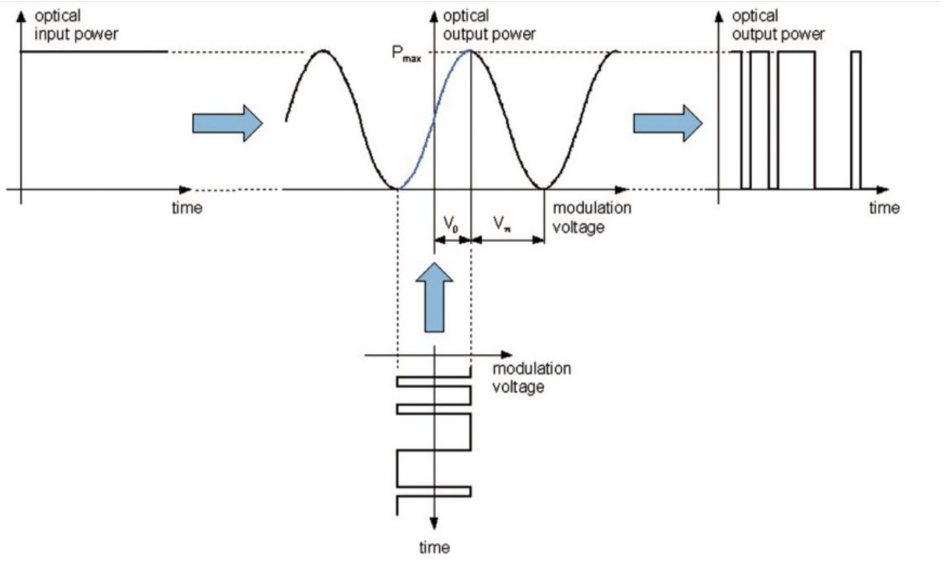


Figure 7: Mach-Zehnder amplitude modulator operation

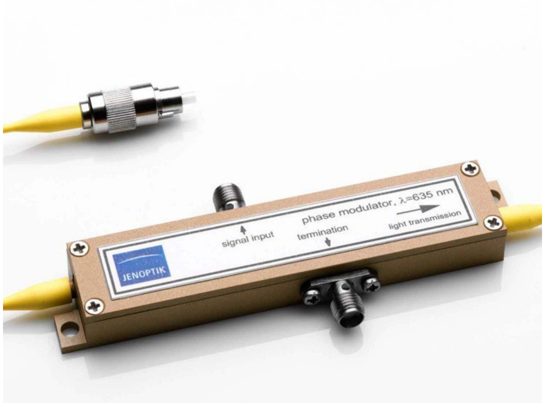


Figure 8: Jenoptik Mach-Zehnder electro-optic modulator

The Model 685 Arbitrary Waveform Generators allows you to create the modulation voltage by generating very narrow pulses (the minimum pulse width is 230 ps) with up to 5 Vpp amplitude. The high amplitude output signal, combined with 110 ps of rise/fall time (5 Vpp @ 2 GHz Bandiwdth), gives you the possibility to directly drive different types of electro-optical modulators without adding an external amplifier.

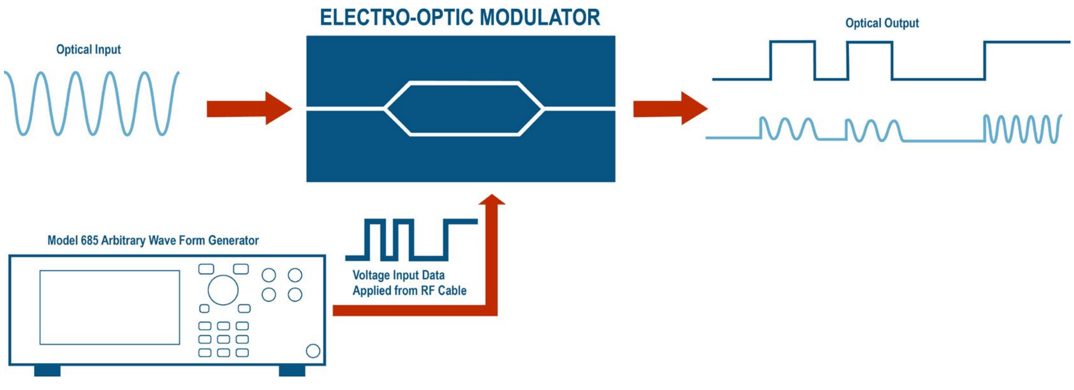


Figure 9: Model 685 & Electro-Optic Modulator connection diagram

Thanks to the True-ARB User Interface, it is possible to easily generate different pulse shapes, giving a more in depth control of optical output signal.

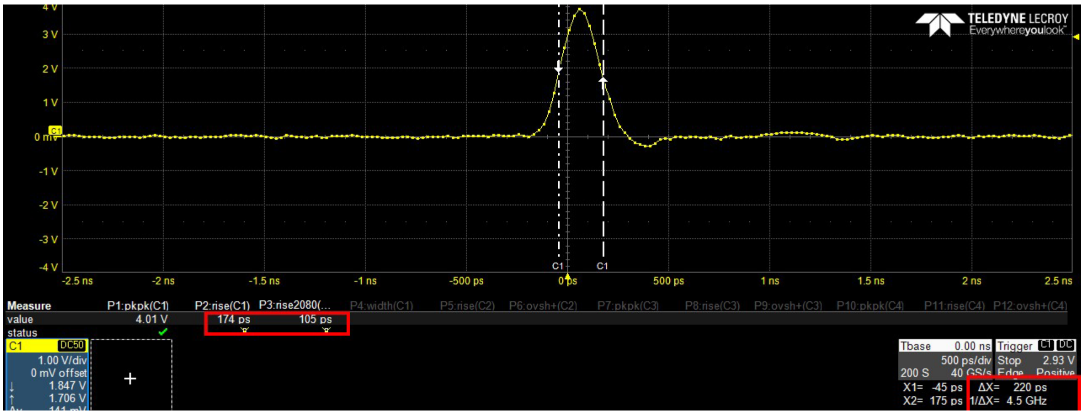


Figure 10: Model 685 Minimum Pulse Width - 230 ps

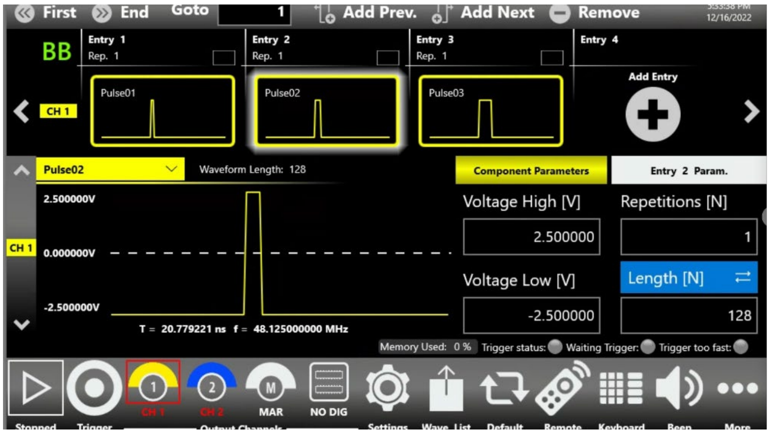


Figure 11: True-Arb UI - Multiple Pulse Generation

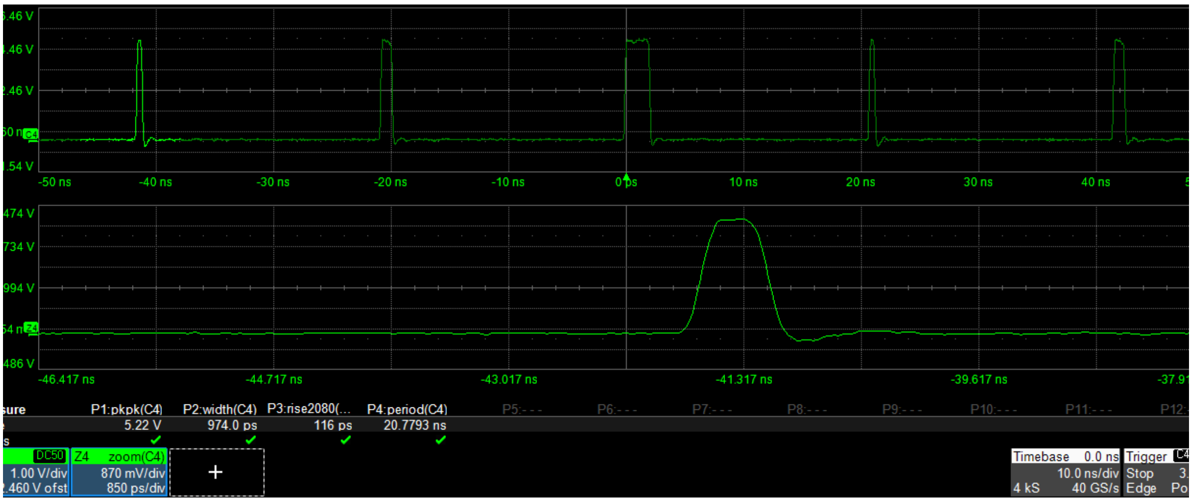


Figure 12: Oscilloscope’s screenshot - Multiple Pulses Generation 5Vpp Amplitude

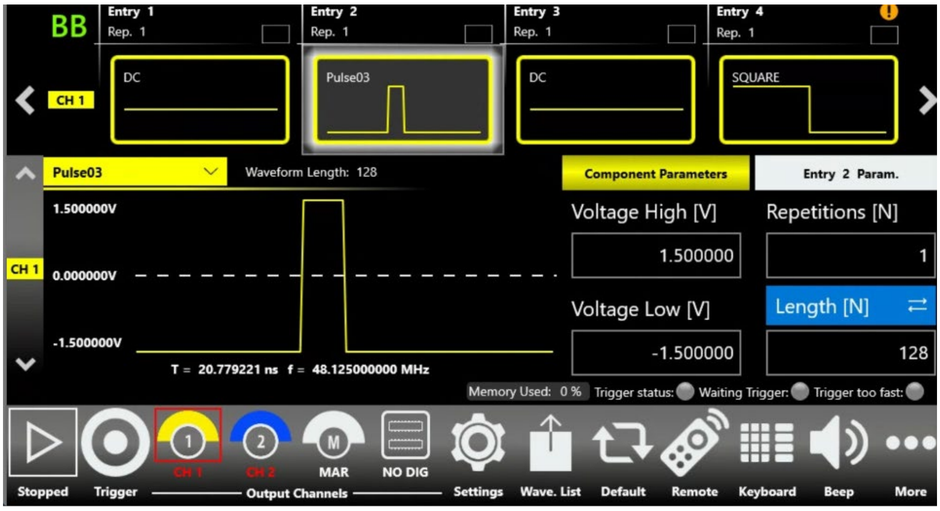


Figure 13: True-Arb settings for electro-optic modulator control

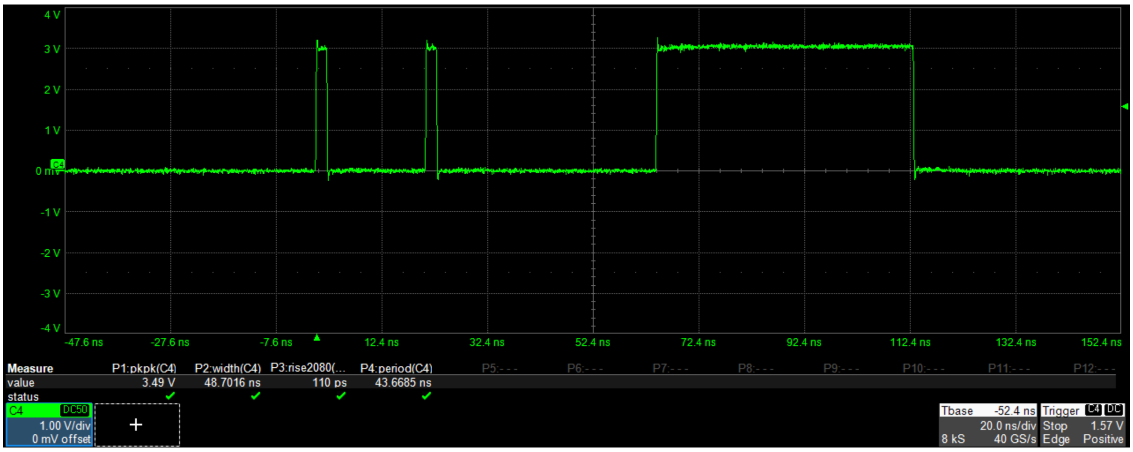


Figure 14: Voltage Input signals for electro-optic modulator with 3.5Vpp amplitude

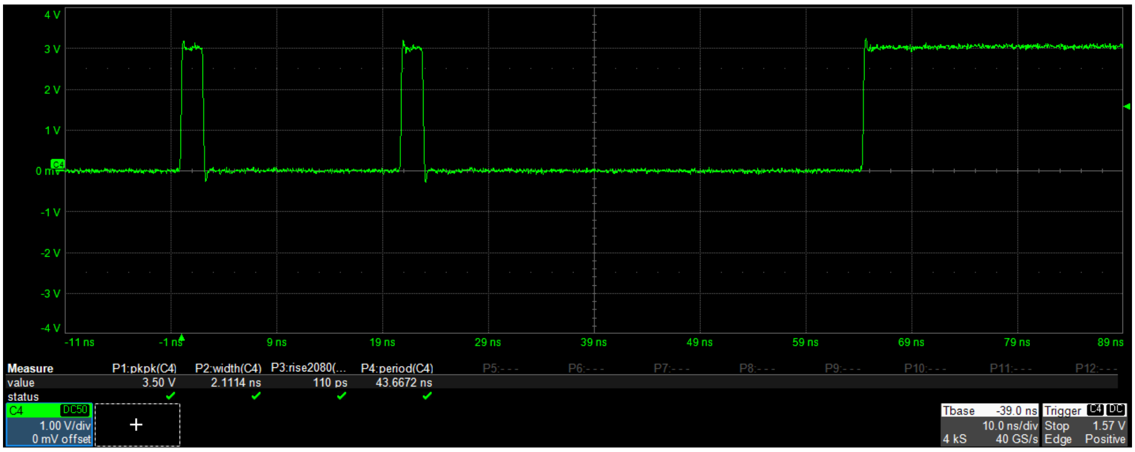


Figure 15: Voltage Input signals for electro-optic modulator with 3.5Vpp - Zoom IN

Quantum Optics

Color centers in diamond are defects in the crystal lattice, where different kinds of atoms replace carbon atoms, and adjacent lattice sites are empty.
Due to their bright single photon emission and optically accessible spins, color centers can be promising solid-state quantum emitters for future quantum information processing and quantum networks.
Two of the most mature systems enabling spin qubits and coherent photons are quantum dots and the nitrogen-vacancy (NV) center in diamond. However, between these two systems, NVs exhibit excellent coherence times exceeding 1s, but lack efficient emission into the zero-phonon line (ZPL) required to yield indistinguishable photons, whereas quantum dots have shown great promise in emission properties but are limited to tens ns coherence times.

This highlights the typical challenges working with solid-state quantum emitters:

- single photon generation
- the emitter spin coherence times.

Recent investigations into group IV vacancy center in diamond in particular SiV ones, show promise results in meeting these field.

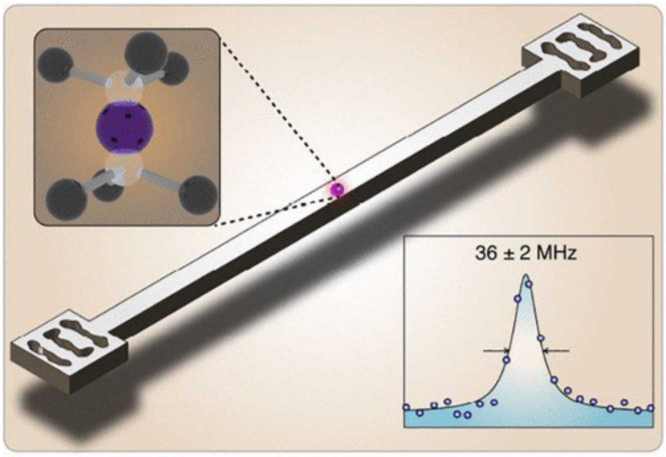


Figure 16: Solid state quantum emitters

Combined with their good spin properties, tin-based vacancy centers are well suited for integrating into nanophotonic platforms because of their strong and stable zero-photon line emission in nanostructures.

Group IV vacancy centers in diamond show excellent optical properties due to their crystallographic symmetry which favors emission into ZPL.
SiV centers show 10 ms coherence times at 100 mK, while SnV has been predicted to give similar times at 2 K - a readily accessible temperature with standard helium cryostats.

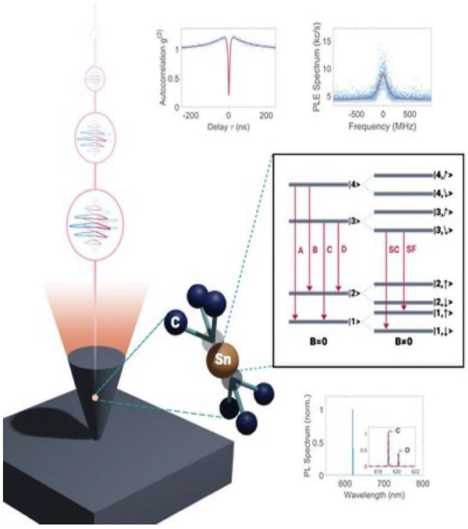


Figure 18: SnV vacancy centers

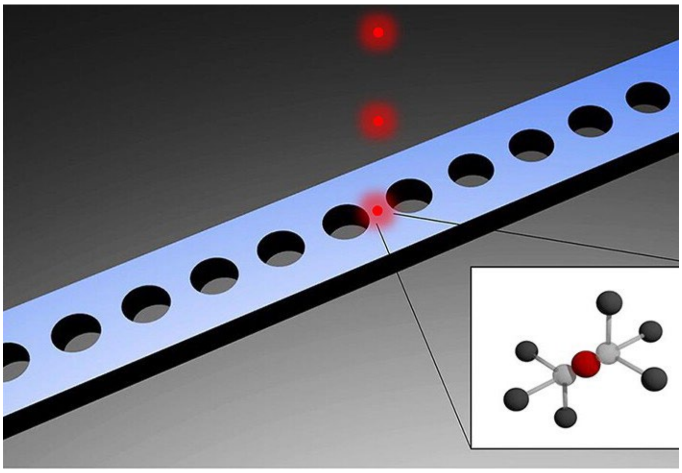


Figure 19: SnV single photon emitter

The Model 685 has been used to control the experimental pulses' sequences used to manipulate single tin vacancy centers in diamonds.

The Model 685 allows generating narrow electrical square pulses with high amplitude (>1.5V) to control an electro-optical amplitude modulator in order to generate short laser pulses.
Using this mechanism, it is possible to generate optical pulses with a close to Gaussian shape exhibiting a full-width-half-maximum as narrow as 280ps.
Furthermore, the Model 685 has been used to drive an electro-optical phase modulator for the generation of frequency sidebands up to about 2GHz, enabling the driving of two optical transitions with phase-stable laser fields.

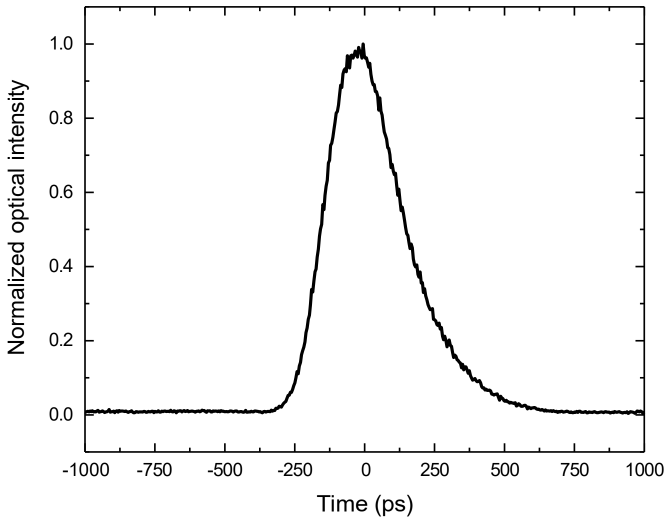


Figure 17: Gaussian optical pulse

The digital output channels of the Model 685, allow to control acousto-optical amplitude modulators, or they are used to generate trigger pulses for timing of experimental sequences.

In the future, it will be necessary the real-time control of the measurement protocols depends on the outcome of a certain readout within the sequence.

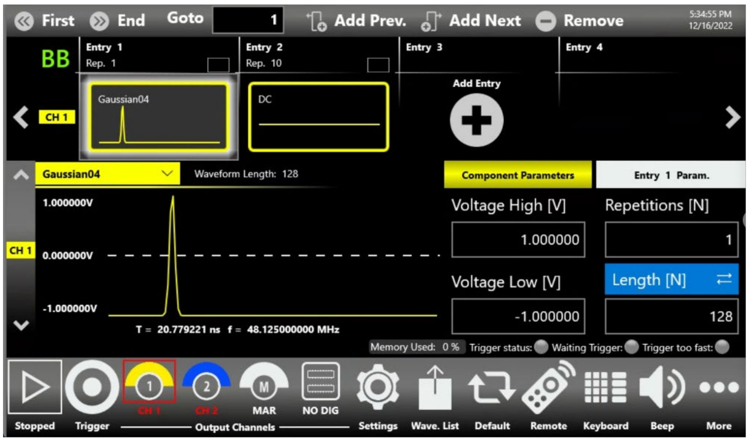


Figure 20: Gaussian optical pulse True Arb Setting

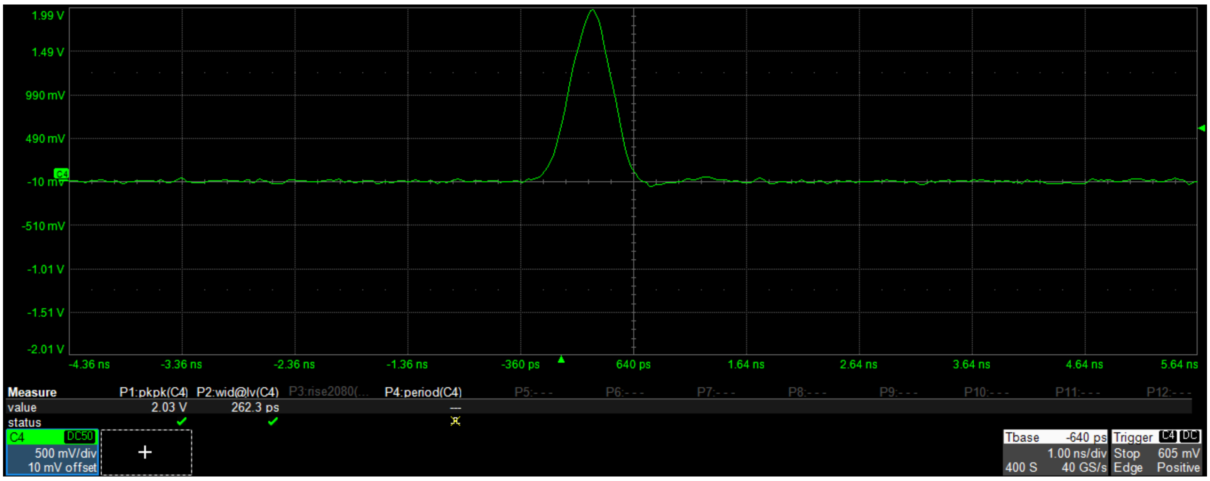
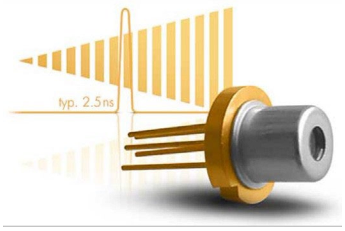


Figure 21: Gaussian pulse - 230 ps Width, 2 Vpp Amplitude

Pulsed Laser Diode Driver



The ability of pulsed laser diodes to provide short pulses of intense power has made them an ideal choice for military applications such as target designating and range-finding.

Indeed, much of the historical motivation for developing these diodes has military roots. However, today's technological improvements and cost reductions are opening new applications in metrology and medicine.

Continuous vs. pulsed operation

Standard laser diodes are designed to emit CW radiation with power from a few milliwatts to a few watts. A pulsed laser operates at a lower duty cycle, so heat removal is less of an issue.
Another design difference between pulsed and CW lasers is that the reflectivity of the pulsed laser's output facet is generally much lower.

Thresholds are kept low on typical CW lasers by limiting the emitting width to 5 to 35 µm. Although laser threshold current is directly proportional to this width, the high gain generated in pulsed lasers allows the width to be increased up to 400 µm with a corresponding increase in peak power. Unfortunately, without precautions, this combination of width and a short resonator at high gain can result in rotating modes in which the circulating power bounces obliquely around inside the gain region rather than straight back and forth between the end facets.

Another factor that affects threshold is that the structure of the pulsed laser is generally configured to provide a beam divergence of less than 25°, compared with the typical CW device that would provide 35°to 45°. The tighter beam is achieved by allowing photons to spread into a "large optical cavity," a weaker waveguide in the transverse direction that reduces the quantity of photons in the gain region. Because no lateral waveguide is built into the pulsed laser structure, the beam divergence in this direction is typically 10°.

Pulsed laser diodes are designed to be driven with high-current pulses, producing short, high-power optical pulses.
To achieve the very high peak optical powers demanded by most applications, the duty cycle is generally kept below 0.1 percent. This means that a 100-ns optical pulse is followed by a pause of 100 µs. For example, a very short pulses available with repetition rates in the kilohertz range. The maximum pulse lengths are typically in the 200-ns range; more common are pulses between 3 and 50 ns.

Electric currents on the order of several tens of amperes are necessary to create these optical pulses. Such high current levels require fast-switching transistors and appropriate circuitry, with all electrical connections kept as short as possible to reduce inductive losses.

So while benefiting from the progress made in CW laser technology, pulsed lasers have been optimized to offer high performance in their unique applications and to facilitate economical production.

When the first commercial GaAs pulsed lasers became available, their wavelength was 905 nm. Fortunately, this is close to the peak responsivity of silicon detectors, and there is a nearby water absorption peak, which reduces ambient light and increases detection sensitivity.
With the advent of new technology and lasers based on different semiconductor materials, it became feasible to produce lasers with a variety of wavelengths.

But lasers operating in the 1550nm range have been receiving more attention because of their superior transmission through fog and smoke. Another distinct advantage is that this wavelength is less hazardous to vision than shorter ones.

Time of flight, other functions

Many applications for pulsed laser diodes are variants of the seminal range finding application, in which target distances are calculated by measuring the flight time of laser pulses reflected or backscattered from the target. Using this principle, some of the more sophisticated instruments can make accurate measurements at distances up to 10 km. Police laser "speed guns," for example, can measure vehicle speed up to 155 mph (250 km/h) at up to 3300 ft (1000 m) with an accuracy of 1 to 3 percent. Unlike conventional radio-frequency speed guns, which measure velocity directly from the magnitude of the Doppler shift in a reflected signal, laser speed guns calculate velocity by comparing distance measurements made at different times.

Since prices came down, eye-safe rangefinders have become available for a variety of recreational activities. Hunters, for example, can buy laser range finding devices to measure the distance to their targets with an accuracy of a meter or two over a range of hundreds of meters.

Similarly, golfers can purchase inexpensive laser rangefinders to try to improve their handicaps. In what some (but not all) might consider a less frivolous application, automotive engineers are developing rangefinders based on pulsed laser diodes, to warn drivers of hazards. Laser range sensors are also widely used.

Pulsed laser diodes provide the optical signal in automotive collision-avoidance systems, used as navigational aids for ships, particularly in ports and harbors; in ceilometers for cloud-based measurement at airports; and in surveying and construction.

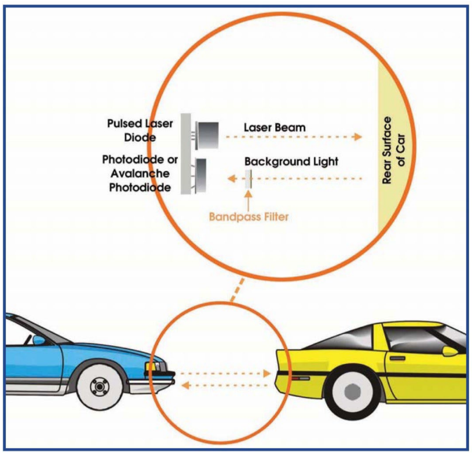


Figure 23: Pulsed laser for collision detection

In a laser safety scanner, pulsed laser diodes create a curtain of light around potentially dangerous areas such as automated production lines. Using coded pulse emission, two-dimensional curtains can be monitored to distinguish between allowed and not-allowed shapes. The high peak power from pulsed laser diodes, when used in combination with avalanche photodiodes, provides the sensitivity necessary to discriminate between shapes. Besides serving as a safety interface, such equipment may also provide remote management and diagnostic functions. Increasingly, similar systems are being deployed on intelligent highways to regulate flow and to identify vehicles at toll booths.

In addition, significant research supports the dramatic wound-healing ability of pulsed laser diodes in medical applications such as laser acupuncture and therapy. Wavelengths in the spectral range of 625 to 905 nm are favored here. The latter wavelength penetrates deeply into tissue and bone to alleviate pain, swelling and inflammation in joints, as well as other afflictions. The laser light must be pulsed to achieve the power necessary for penetration and absorption without damaging the cells.

The generation of short, powerful pulses using laser diodes represents an enabling technology for a variety of applications that cannot be addressed with CW laser diodes, for either technical or economic reasons. Laser Components and other manufacturers have developed commercial products and offer devices at 850, 905 and 1550 nm for such applications with a wide range of output powers and emitting areas, both as single emitters and as stacked devices.

The Model 685 allows you to directly control the pulsed laser diode or to indirectly control it using an electro-optic or acousto-optic modulator.

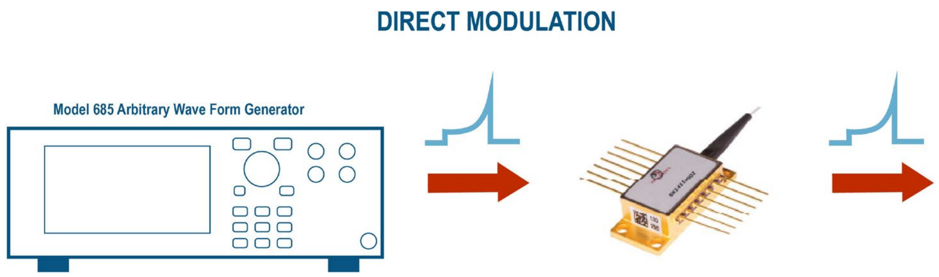


Figure 24: Direct Modulation - Pulsed Laser Diode Driver

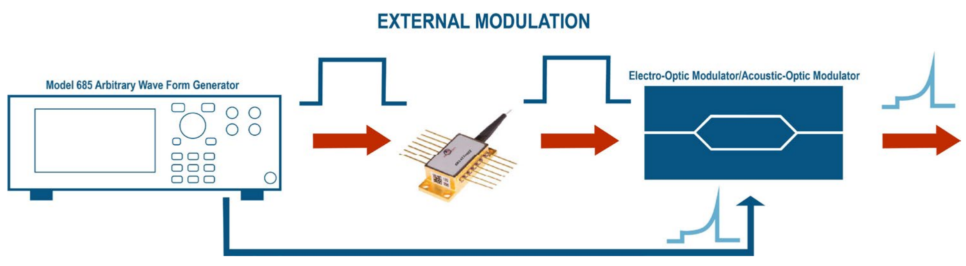


Figure 25: External Modulation - Pulsed Laser Diode Driver

The pulsed laser diodes need to be driven with high amplitude and very short and narrow pulses: the Model 685 can create rectangular, gaussian, exponential shape pulses with an amplitude up to 5Vpp, 110 ps of rise and fall time and a minimum pulse width of 230 ps.

The following screenshots testify the possibility of creating easily the different pulses with True-Arb UI and then reproducing them through an oscilloscope.

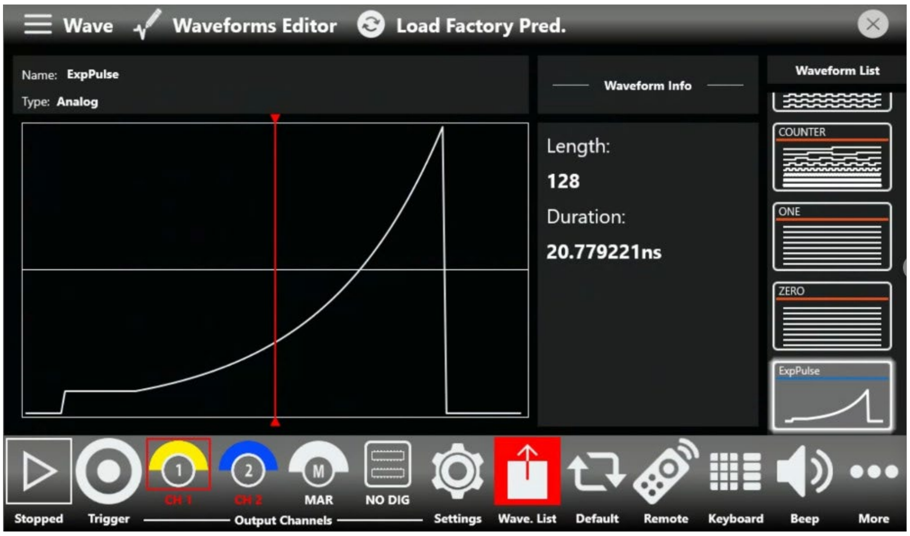


Figure 26: Gaussian pulse - 230 ps Width, 2 Vpp Amplitude

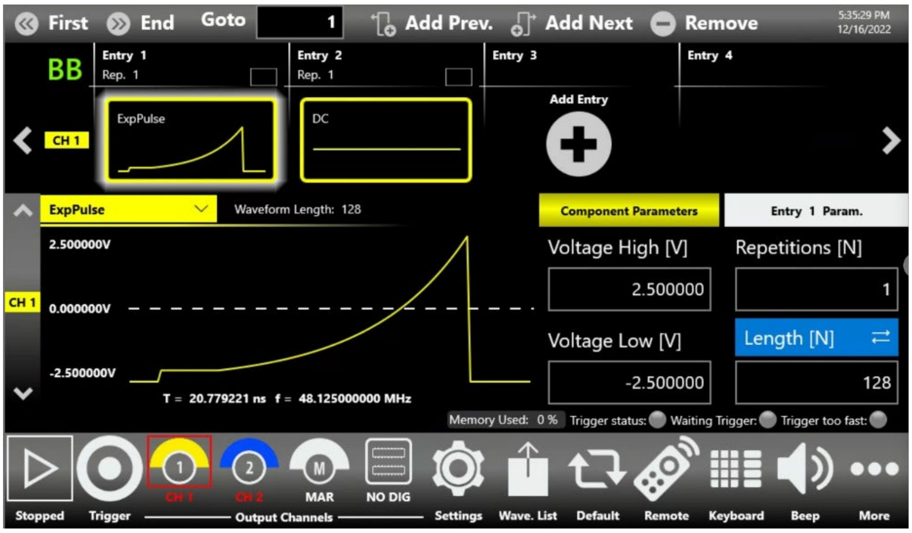


Figure 27: Gaussian pulse - 230 ps Width, 2 Vpp Amplitude

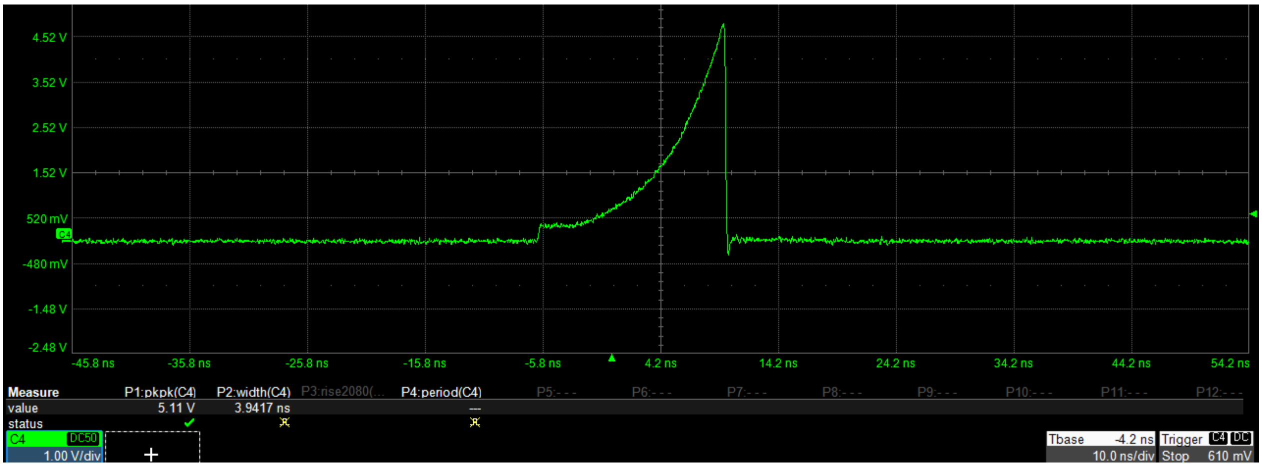


Figure 28: Gaussian pulse - 230 ps Width, 2 Vpp Amplitude

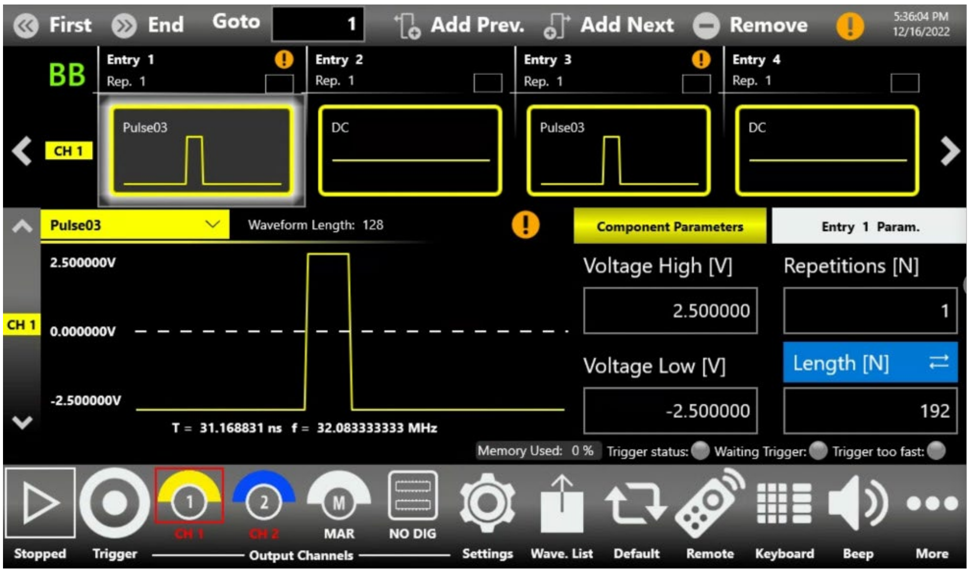


Figure 29: Rectangular pulses for pulsed laser diode control

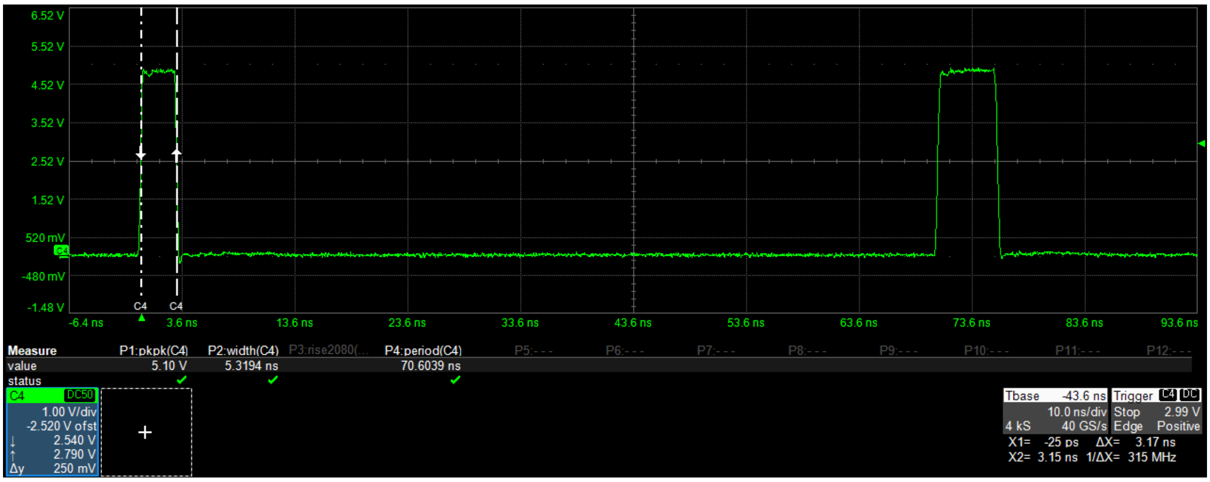


Figure 30: 5 Vpp, 3ns Rectangular pulses

Conclusion

The Model 685 provides you an extremely flexible and high-performance solution to generate all types of pulses or signals that are needed to meet today's challenges in quantum optics, photonics and laser applications.

The new industry's requirements and the development of new products increase the demand for cutting-edge test-equipment instrumentation to satisfy the most demanding applications and the latest scientists' ideas.