VII-3 A SUBNANOSECOND X-BAND PULSE MODULATOR

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Step and impulse waveforms are serving an increasingly important role in modern microwave technology. Historically, radar has been the most important application for abruptly changing waveforms. An important new application is time-domain reflectometry, where abrupt base-band waveforms are used to resolve transmission line discontinuities. Baseband waveforms (those whose spectrum begins essentially at zero frequency) are particularly useful for observing discontinuities in characteristic impedance. When frequency sensitive discontinuities are observed, however, the resolution will depend on the amount of high-frequency energy available in the waveform.

Greater versatility is obtained by the ability to apply step or pulse modulation to a carrier. In this way useful spectrum can be translated to higher RF bands, where small inductances and capacities appear as larger discontinuities. A still more important advantage is that carrier waveforms can be radiated from an antenna for free-space measurements, and for locating internal discontinuities in dielectric materials remote from the signal source.

This paper discusses improved techniques for producing short carrier pulses using semiconductor diodes. The basic technique has been described by Dietrich and Sharpless,[1] who reported carrier pulses characterized by a pulse width τ (ns) and carrier frequency f_0 (GHz) such that the product τf_0 has a value between 10 and 15. (Here τ is measured 20 dB below the peak of the pulse.) More recently, Dawson and DeLoach[2] reported X-band pulses using unpackaged diodes with a corresponding τf_0 product of about 10. In the work reported here, a τf_0 product of 6 was obtained with commercially available packaged diodes.

The value of semiconductor diodes for fast modulator application is that the junction capacity can be used for switching without driving the diode into heavy conduction; therefore, the switching speed can be extremely fast. Also, the relatively small voltage required for switching allows them to be operated at high PRF. The main difficulty encountered is due to fairly high Q resonances associated with the diode package. The energy stored in the package reactances must be dissipated rapidly to utilize the inherent switching speed of the diode junction. The use of unpackaged diodes is one way to alleviate this problem.[1,2] However, it is possible to obtain subnanosecond carrier modulation with commercially available diodes, as will be demonstrated.

The theoretical limit on pulse width for a 4-GHz bandwidth-limited X-band pulse, measured 20 dB below the peak, is 0.4 ns.[3] The photograph in Fig. 1 shows a pulse generated in X-band waveguide with a carrier frequency of 9.8 GHz, the time base of 0.23 ns/division. The pulse rises and falls in approximately two carrier cycles (0.2 ns) and the overall pulse duration is about six carrier cycles (0.6 ns) measured at points 20 dB below the peak. The baseband drive pulse is produced with a step-recovery diode, while the modulating diode is MA 4054A1.

The photograph in Fig. 1 was taken on a 3-GHz sampling scope. By using the X-band carrier to synchronize a 25-MHz tunnel diode oscillator, the latter was locked to a subharmonic frequency f'. The f' frequency was then used as the PRF and was also used to synchronize the sampling scope. In this way a coherent picture of an X-band pulse was obtained on a "low-frequency" sampling scope.

In the drawing of the pulse modulator shown in Fig. 2, two basic parts are indicated: a diode which acts as a gate to the CW carrier; and a bandstop filter, which matches to the drive pulse line. The main purpose of the bandstop filter is to block frequencies in the carrier pulse spectrum. Equally important, however, is that the filter provide a stable reference plane to the diode--one whose motion with frequency is as small as possible. A matched bandstop decoupling filter is superior to conventional low-pass or resonant-choke bypass networks because it provides minimal capacitive loading for the baseband frequencies in the modulating pulse.

A three-stub, quarter-wavelength coupled filter has been designed by the method of Schiffman and Matthaei.[4] The development of the filter is shown in Fig. 3. Three direct-coupled stubs form the prototype filter. To this are added four unit elements on the right. All elements are $\lambda/4$ at the center of the stop band, which is also the carrier frequency. The diode is attached at the left where the short-circuit reference plane in the stopband is not influenced by the line lengths. Using Kuroda's identity (see Ref. 4) it is now possible to transform the four line segments through the filter without changing the transient or steady-state properties of the network. The resulting filter, shown in Fig. 3(c), has the same short circuit reference plane as the prototype in Fig. 3(b), but the stubs are separated and well removed from the diode for ease of construction. Note that the transformed line section next to the diode has low characteristic impedance, and can be relized with a solid coaxial section compatible with the shape of the diode package. The remaining portion of the filter can be photoetched. When the diode is inserted in the end of the coaxial section, its depth can be varied to adjust the diode equivalent circuit. A photograph of the completed modulator is shown in Fig. 4. It will be noted that the 4.49 Z_0 stub was omitted in the bandstop filter, since it is insignificant.

In the quiescent condition, the switching diode is series resonant at the frequency of the carrier, which causes the carrier to be reflected. Control of the series resonant frequency is accomplished with diode selection, position in the mount, and with bias. To open the switch, the diode is pulsed into light conduction and becomes parallel resonant. Generally, extra shunt capacity is required, which is obtained with the support post or spacer shown in Figs. 2 and 4. Because the diode is tightly coupled to the propagating waveguide mode, both diode resonances have low external Q. The effective bandwidth of the switch is thus very broad, which causes stored energy to be dissipated rapidly in both the transmitting and reflecting states. In the final circuit, a 2 V pulse was sufficient to switch states.

The main application for short RF pulses is RF time-domain reflectometry. The demand for RF time-domain reflectometry results from an ever-increasing usage of nonmetallic materials in critical structural applications. Such materials increase the importance of microwaves for nondestructive testing and defect location. The short carrier pulses under discussion have been used successfully to resolve two objects separated by as little as one carrier wavelength (about 1 inch in air).

In summary, a simple method for generating extremely short carrier pulses has been described. The generated pulse width is close to the theoretical limit for a bandwidth limited device. The described method employs commercially available diodes and a novel decoupling filter. The authors gratefully acknowledge the assistance given by Dr. Leo Young, and thank him for his encouraging suggestions.

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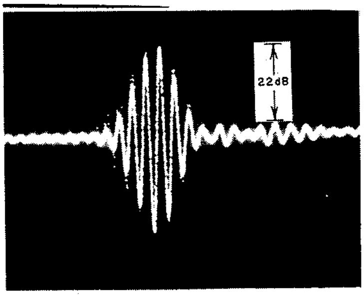

FIG. 1 - A Photograph of an X-Band Pulse consisting of 6 cycles. Time Base: 0.25 Nanoseconds/cm. Peak Power of 10 MW

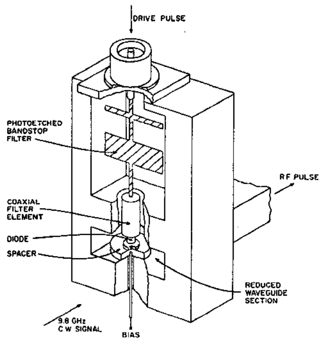

FIG. 2 - Cutaway drawing of the diode mount and bandstop decoupling filter. The waveguide dimensions are 0.9 x 0.1 inch. The diode used is MA4054A1

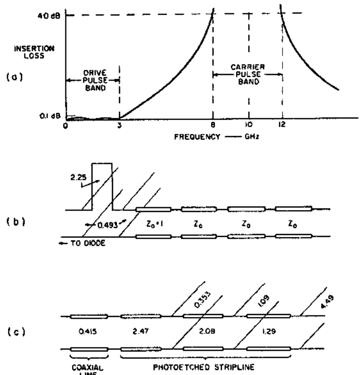

FIG. 3 - Bandstop filter design. A base-band bandwidth of 3 GHz is provided for drive pulse. The X-band pulse bandwidth is 4 GHz. All line impedance are normalized to 1 ohm

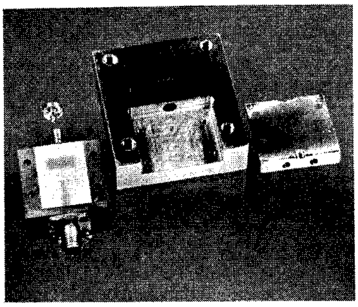

FIG. 4 - View of the Pulse Modulator showing the Bandstop Decoupling Filter. The Waveguide Opening is 0.9 x 0.1 inch