E_p to E_c traces were obtained with an additional 30 db of rf attenuation in the circuit above that used in obtaining the crosstalk traces.

Conclusions

It appears that the finline coupler may be of considerable utility as a basic ultra-bandwidth circuit element which may be used as a variable coupler, an hybrid junction, or as a polarization selector. Other applications will probably be found.

Acknowledgment

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Microwave Traveling-Wave Tube Millimicrosecond Pulse Generators

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Summary—For some time, short pulse techniques have played a useful part in the microwave art. In order to obtain better resolution, equipment for generating and viewing microwave pulses about six millimicroseconds long was developed and described previously. The regenerative pulse generator in that equipment was rather complex and difficult to build and adjust. A much simpler generator of pulses with about the same time duration is now being used. It produces short pulses by properly gating a conventional microwave signal source with a traveling-wave amplifier having suitable transient voltages applied to both its helix and its beam-forming electrode. It is easier to construct and operate, requires fewer components, and gives a more stable output. It can be used at any frequency where a signal source and a traveling-wave amplifier are available. The pulse frequency can be set anywhere within the amplifier bandwidth.

Both generators are described and compared. Equipment for receiving, displaying, and measuring the pulses is also briefly discussed. Pulse shapes and resolutions are shown on oscilloscope photos.

Introduction

PULSE TECHNIQUES have been useful at microwave frequencies for some time. In many of their applications, the need for greater resolution has led to the use of shorter and shorter pulses. Recently, equipment has been described which generates and displays 9,000-mc pulses having a length of about 6 millimicroseconds (mμsec).[1] Such pulses occupy a few feet of path length in a transmission medium, so good resolution is obtained. They have been used for measuring radio repeater waveguides and antennas and have found many applications to multimode waveguide studies.

Regenerative Pulse Generator

In the original equipment, these short pulses were produced by a regenerative pulse generator suggested by C. C. Cutler of these Laboratories.[2] This was a very useful device, but rather complicated and hard to build and adjust. A brief description of it will permit comparisons with a simplified pulse generator which has recently been developed.

Fig. 1 is a block diagram of the regenerative pulse generator. The fundamental part of the system is the feedback loop drawn with heavy lines in the lower central part of the figure. This includes a traveling-wave amplifier, a waveguide delay line about sixty feet long, a crystal expander, a band-pass filter, and an attenuator. This combination forms an oscillator which produces very short pulses of microwave energy. Between pulses, the expander makes the feedback loss too high for oscillation. Each time the pulse circulates around the loop it tends to shorten, due to the greater amplification of its narrower upper part caused by the expander action, until it uses the entire available bandwidth. A 500-mc gaussian band-pass filter is used in the feedback loop of this generator to determine the final bandwidth. An automatic-gain control operates with the expander to limit the pulse amplitude, thus preventing amplifier compression from reducing the available expansion.

To get enough separation between outgoing pulses for reflected pulse measurements with waveguides, the repetition rate would need to be too low for a practical delay line length in the loop. Therefore a 12.8-mc fundamental rate was chosen, and a gated traveling-wave tube amplifier was used to reduce it to a 100-kc rate at the output. This tube is kept in a cutoff condition for 127 pulses, and then a gate pulse restores it to the normal amplifying condition for fifty millimicroseconds (mμsec), during which time the 128th pulse is passed on to the output of the generator, as shown on Fig. 1.

The synchronizing system is also shown on Fig. 1. A 100-kc quartz crystal controlled oscillator with three cathode follower outputs is the basis of the system. One output goes through a seven-stage multiplier to get a 12.8-mc signal, which is used to control a pulser for

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[1] A. C. Beck, "Microwave testing with millimicrosecond pulses," Trans. IRE, vol. MTT-2, pp. 93–99; April, 1954.

[2] C. C. Cutler, "The regenerative pulse generator," Proc. IRE, vol. 43, pp. 140–148; February, 1955.

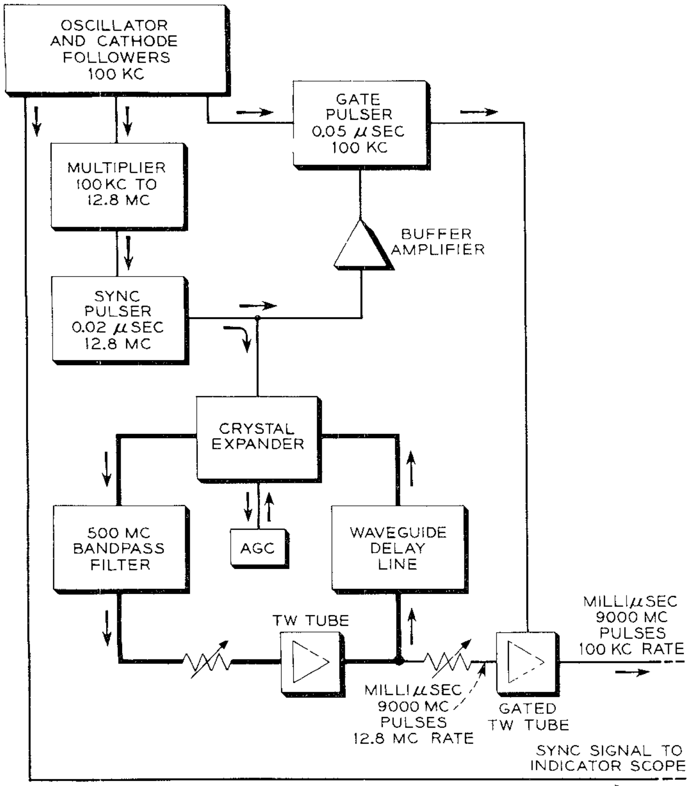

Fig. 1—Block diagram of the regenerative pulse generator.

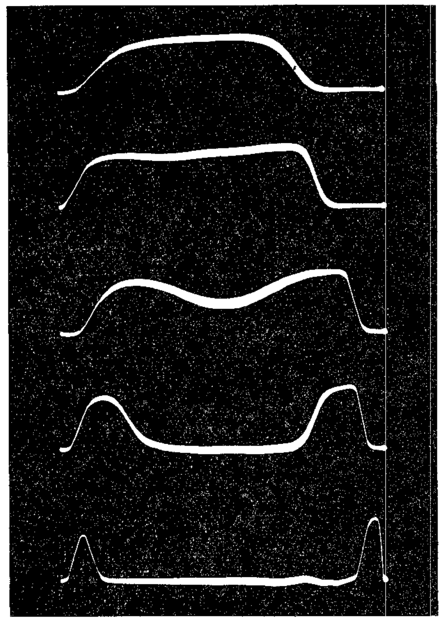

Fig. 2—Envelopes of microwave pulses at the output of a traveling-wave amplifier with continuous wave input and helix gating. The gating voltage is higher for the lower traces.

synchronizing the main loop. Another output controls the gate pulser for the output traveling-wave amplifier. Accurate timing of the gate pulse is obtained by adding the 12.8-mc pulses through a buffer amplifier to the gate pulser. The third output synchronizes the indicator oscilloscope sweep to give a steady pattern on the screen.

Although this equipment was fairly satisfactory and served for many testing purposes, it was rather complex and there were some problems in its construction and use. It was difficult to obtain suitable crystals to match the waveguide at low levels in the expander, making it even more difficult to build this type of pulse generator for higher frequency ranges. Stability also proved to be a problem. The frequency multiplier had to be very well constructed to keep its output steady. The gate pulser also required care in design and construction in order to get a stable and flat output pulse. It was rather troublesome to keep the gain set for proper operation, and gate pulse time adjustment required some attention. For these reasons, and in order to get a smaller, lighter, and less complicated pulse generator, work has been carried out to produce pulses of about the same length by a simpler method.

Double-Gated Traveling-Wave Tube Pulse Generator

If the gated output amplifier of the regenerative pulse generator just described were to have a cw signal input, a pulse of microwave energy would appear in the output at the time of normal amplification. The gating pulse is applied to the beam-forming electrode of the tube to obtain gating action. If the beam-forming electrode could be pulsed from cutoff to normal operating potential for a very short time, very short pulses of output energy could be obtained from a continuous input signal. However, it is difficult to obtain millimicrosecond video gating pulses of sufficient amplitude for this purpose at a 100-kc repetition rate.

It was observed during adjustments of the gated amplifier with cw input that too high a positive gating voltage caused the output signal pulse envelope to dip in the middle. Further increase in this gating voltage caused this dip to deepen until two separate shorter pulses appeared with a space between them. The explanation is that the tube amplifies normally only when the beam forming electrode is within a small voltage range around its rated dc operating value. For voltages either above or below this range, the tube is cut off. When the gate voltage goes through this range into the cutoff region beyond it, and back again, two pulses are obtained, one during a small part of the rise time and the other during a small part of the return time. If the rise and fall times are steep, very short pulses can be obtained. Experiments confirmed this explanation, but driving the beam-forming electrodes of our tubes into the positive region beyond the normal value, even for very short times, caused loss of emission and shortened tube life.

Therefore it was decided to try pulsing the helix through its operating range in the same manner. Fig. 2 shows the resulting pulse envelopes photographed from the indicator scope screen when this is done. For the top trace, the helix was biased 300 volts negatively from its normal operating potential, then pulsed to its correct operating range for about 80 mμsec, during which time normal amplification of a cw input signal was obtained. The effect of further increasing the helix video pulse amplitude in the positive direction is shown by the succeeding lower traces. The envelope dips in the middle, then two separated pulses appear, one during a part of the rise time and one during a part of the fall time of helix voltage. The pulses shown on the bottom trace have shortened to about six mμsec in length. The helix pulse had a positive amplitude of about 500 volts for this trace. Continued helix pulsing caused no tube damage.

Since only one of these two pulses can be used to get the desired repetition rate, it is necessary to eliminate the other pulse. This is done in a similar manner to that used for gating out the undesired pulses in the regenerative pulse generator. However, it is not necessary to use another amplifier, as was required there, since the same tube can be used for this purpose, as well as for producing the microwave pulses. Its beam-forming electrode is biased negatively about 250 volts, with respect to the cathode, and is pulsed to the normal operating potential for about 50 mμsec during the time of the first short pulse obtained by gating the helix. Thus, the beam-forming electrode potential has been returned to the cutoff value during the second helix pulse, which is therefore eliminated. In order to time these two gating voltages correctly, about four feet of coaxial cable provides the right delay in the helix pulser connection so that its first pulse occurs during the beam-forming electrode pulse, and the tube is cut off during the second helix gated pulse.

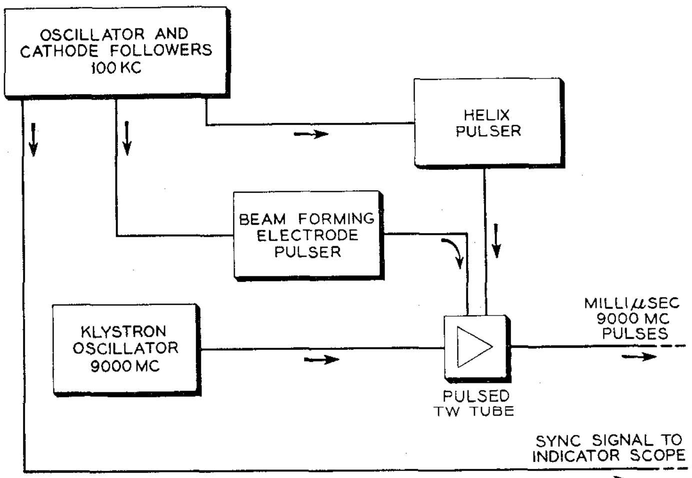

Fig. 3—Block diagram of the double-gated traveling-wave tube millimicrosecond pulse generator.

A block diagram of the resulting double-gated pulse generator is shown in Fig. 3. Comparison with Fig. 1 shows that it is simpler than the regenerative pulse generator, and it has also proved more satisfactory in operation.

The pulse center frequency is shifted from that of the klystron oscillator by this helix gating process. An oversimplified but helpful explanation of this effect can be obtained by considering that the microwave signal voltage on the helix causes a bunching of the electron stream. This bunching has the same periodicity as the signal voltage when the dc helix potential is held constant. However, since the helix voltage is continuously increased in the positive direction during the time of the first pulse, the average velocity of the last bunches of electrons is made higher than that of the earlier bunches in the pulse, because the later electrons come along at the time of higher positive helix voltage. This tends to shorten the series of bunches, resulting in a shorter wavelength at the output end of the helix and therefore a higher output frequenty. On the second pulse, obtained when the helix voltage returns toward zero, the process is reversed, the bunching is stretched out, and the frequency is decreased. This second pulse is, however, gated out in this arrangement by the beam-forming electrode pulsing voltage. The result for this particular tube and pulse length is an effective output frequency approximately 150 mc higher than the oscillator frequency, but this figure is not constant over the range of pulse frequencies available within the amplifier bandwidth.

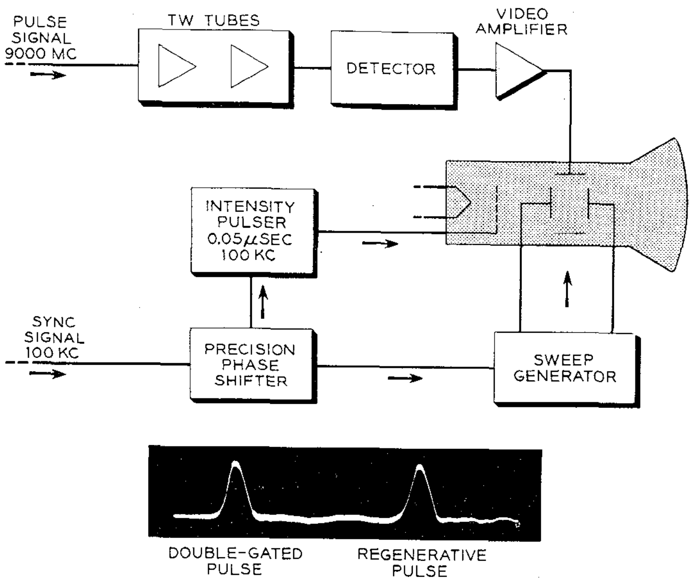

Fig. 4—Block diagram of millimicrosecond pulse receiver and indicator. The indicator trace photograph shows pulses from each type of generator.

Receiver and Indicator

The receiving equipment is shown in Fig. 4. It originally consisted of three traveling-wave tube amplifiers in cascade, but now only two are used, since the gain obtained with these tubes is higher than was originally anticipated. A wide-band detector and a video amplifier then follow, and the signal envelope is displayed by connecting it to the vertical deflecting plates of a 5 XP type oscilloscope tube. The video amplifier now consists of two Hewlett Packard wide-band distributed amplifiers, having a baseband width of about 175 mc. The second one of these has been modified to give a higher output. The sweep circuits for this oscilloscope have been built especially for this use, and produce a sweep speed in the order of 6 feet per microsecond. An intensity pulser is used to eliminate the return trace. These parts of the system are controlled by a synchronizing output from the pulse generator 100 kc oscillator. A precision phase shifter is used at the receiver for the same purpose that a range unit is employed in radar systems. This has a dial, calibrated in millimicroseconds, which moves the position of a pulse appearing on the scope and makes accurate measurement of pulse delay time possible.

Fig. 4 also shows the appearance of the pulses obtained with this equipment. The pulse on the left-hand side of this trace came from the newer double-gated pulse generator, while the pulse on the right was produced by the regenerative pulse generator. It can be seen that they appear to have about the same pulse width and shape. This is partly due to the fact that the video amplifier bandwidth is not quite adequate to show the actual shape, since in both cases the pulses are slightly shorter than can be correctly reproduced through this amplifier. The ripples on the base line following the pulses are also due to the video amplifier characteristics when used with such short pulses.

Resolution and Measuring Range

Fig. 5 shows a piece of equipment which was placed between the pulse generator and the receiver to show the resolution which can be obtained. This hybrid junction has its branch marked 1 connected to the pulse generator and branch 3 connected to the receiver. If the two side branches marked 2 and 4 were terminated, substantially no energy would be transmitted from the pulser straight through to the receiver. However, a short circuit placed on either side branch will send energy through the system to the receiver. Two short circuits were so placed that the one on branch 4 was 4 feet further away from the hybrid junction than that on branch 2. The pulse appearing first is produced by a signal traveling from the pulse generator to the short circuit on branch 2 and then through to the receiver, as shown by the path drawn with short dashes. A second pulse is produced by the signal which travels from the pulse generator through branch 4 to the short circuit, and then to the receiver as shown by the long dashed line. This pulse has traveled 8 feet further in the waveguide than the first pulse. This would be equivalent to seeing two radar echoes from targets a little more than 4 feet apart. Resolution tests made in this way with the pulses from the regenerative pulse generator, and from the double-gated pulse generator, are shown on Fig. 5. With our video amplifier and viewing equipment, there is no appreciable difference in the resolution obtained using either type of pulse generator.

The measuring range is determined by the power output of the gated amplifier at saturation and by the noise figure of the first tube in the receiver. In this equipment the present saturation level is about 1 watt, and the noise figure of the receiver tube is rather poor, so that we obtain about a 70-db measuring range. Although this is less than radar equipment needs, it is sufficient for many measurement purposes.

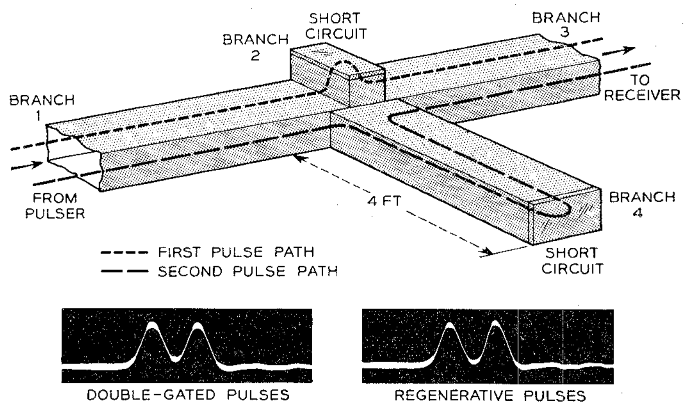

Fig. 5—Waveguide hybrid circuit used to demonstrate resolution of millimicrosecond pulses. Trace photographs of pulses from each type of generator are shown.

Conclusion

The double-gated pulse generator has a number of advantages when compared with the regenerative pulse generator. It is easier to construct and operate, is smaller and lighter in weight, requires fewer components, and gives a more stable output. Pulse length is about the same. It can be used at any frequency where a signal source and a traveling-wave amplifier are available, and the frequency can be set anywhere within the range of the amplifier by tuning the klystron oscillator.

The high resolution obtainable with such short pulses provides information difficult to obtain by any other means. This method of producing the pulses, by considerably simplifying the equipment, makes millimicrosecond pulse techniques more readily attainable at microwave frequencies.