Generating ultra-short microwave pulses

Cancellation technique using readily-obtainable components

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During an investigation into the behaviour of microwave radar receivers in the presence of high energy leakage spikes from the transmitter via the duplexer, a generator of very short pulses of microwave energy was needed. Standard magnetrons and modulators are not capable of producing directly the six to seven nanosecond pulses available by the method described.

THE PROBLEM OF GENERATING consistent-energy pulses at microwave frequencies a few nanoseconds long was approached by employing a pulse cancellation technique. The frequency employed was in X-band (8.2 to 12.4GHz), but the technique is also applicable to other microwave bands. A 160ns-long r.f. pulse was split in a "magic T", and the two halves recombined in antiphase after travelling different path lengths. Fig. 1 shows how this was achieved by using two short-circuited arms of different lengths on a magic T. The result was that the centre portion of the magnetron pulse cancelled leaving short pulses corresponding to the leading and trailing edges of the original pulse. The trailing edge pulse was removed by means of a pulsed p-i-n diode switch. A CV370 magnetron supplied 5kW peak pulses at 1,000 pulse/sec.

The electric field of the magnetron pulse may be represented by

$$E(t)=2A(t)\sin(\omega t+\theta)$$

where $2A$ is the amplitude of the magnetron pulse, and is a function of time, ω is the angular frequency, and θ is an arbitrary phase angle. After travelling different path lengths, the two cancelling pulses are displaced in time by Δt, and the cancelled pulse is then

$$\tfrac{1}{2}[E(t+\Delta t)-E(t)]$$

where the factor ½ allows for the 6dB loss of power in the magic T. Substitution gives

$$(A+a)\sin(\omega t+\theta+\alpha)-A\sin(\omega t+\theta)$$

where a is the instantaneous amplitude difference between the two pulses and α their phase difference, nominally $2n\pi$ but which varies over the pulse length due to phase and frequency modulation. By appropriate manipulation this can be shown to be of the form $B\sin(\omega t+\beta)$, with

$$B=\sqrt{4A(A+a)\sin^2(\alpha/2)+a^2}$$

$$\text{and } \beta=\theta+\tan^{-1}\left[\frac{(A+a)\sin\alpha}{A(\cos\alpha-1)+a\cos\alpha}\right]$$

All the terms A, a, α, θ and therefore B and β are functions of time. The situation is illustrated in the diagrams of Fig. 2. The trailing edge pulse is longer and of lower amplitude than the leading edge pulse because the magnetron fall time is much slower than its rise time.

The amplitude of the short pulse is given by the expression for B and in the

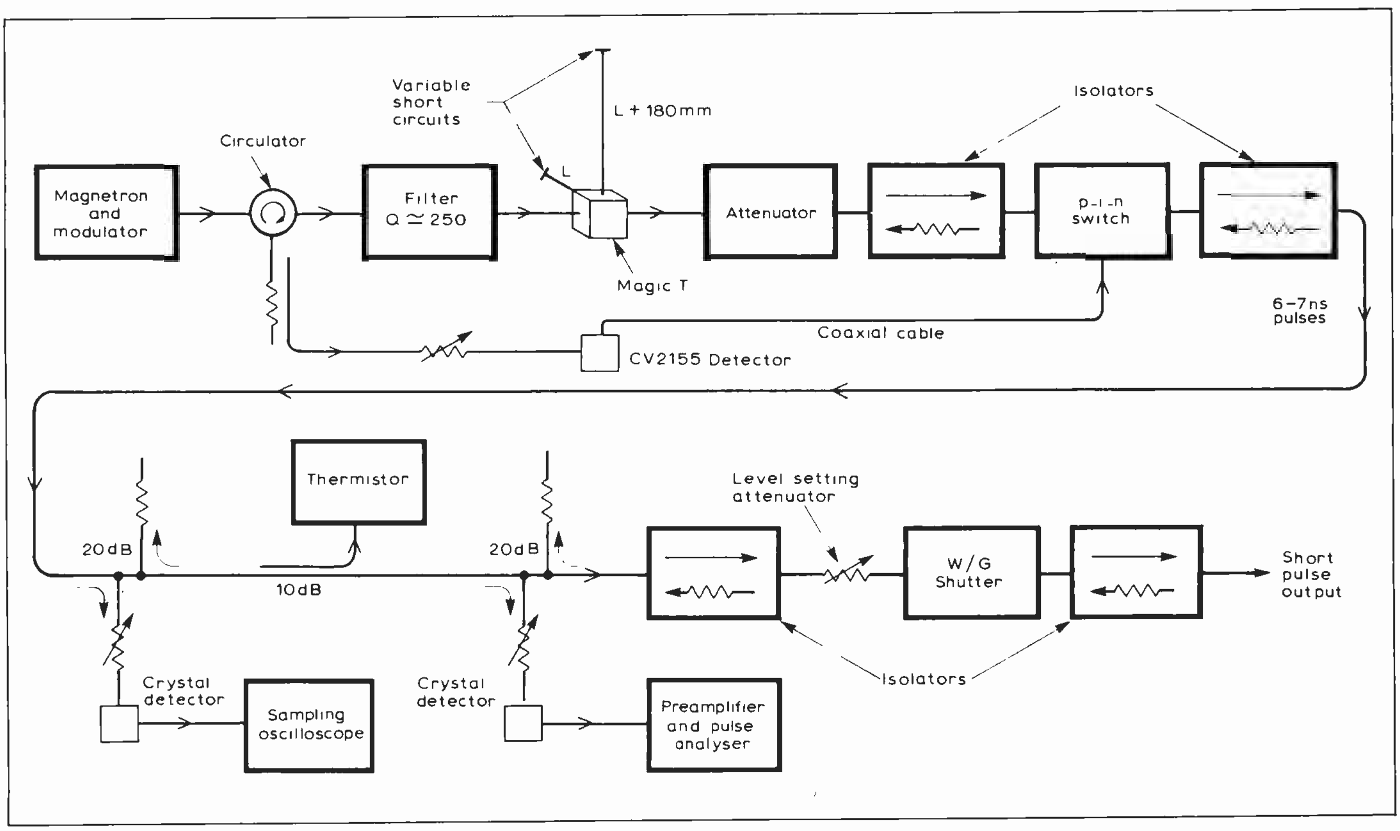

Fig. 1. *Waveguide layout for generating ultra-short pulses by cancelling differentially delayed pulses.*

ideal case of no phase or frequency modulation, $\alpha = 2n\pi$ and then $B = a$; otherwise $B > a$. In the region where $a = 0$, cancellation may be incomplete due to phase differences and the output will then be $B = 2A\sin(\alpha/2)$.

For high amplitude and minimum pulse length a fast rate of rise and minimum phase modulation of the magnetron pulse are required. The short pulse is centred on the region of maximum rate of change of the magnetron pulse's electric field. This is likely to be near the 50% field (25% power) level and there will not be a simple relation between the magnetron rise time from 10 to 90% power levels and the length of the short pulse.

In practice the apparently simple cancellation technique was complicated by significant direct leakage between the decoupled arms of the magic T, the phases of both reflected pulses had to be adjusted so that all three signals cancelled. The poor match of the magic T for the reflected pulses in the short circuited arms made the first re-reflected pulses significant, and modified the pulse shape.

It should be possible by the use of suitably placed mismatches to change the magnetron output coupling during the build-up of oscillation and hence modify the leading edge of the pulse. This was tried but results were inconclusive and the matter was not pursued.

Among the problems encountered were the elimination of the second or trailing edge pulse, and the reduction of the spread of pulse energies. A varactor diode switch was initially tried for the attenuation of the trailing edge pulse and behaved well at low levels. However it proved to have inadequate attentuation at the power levels required and was replaced by a p-i-n diode switch which has proved satisfactory. The switching pulse for this was obtained from the magnetron output via a CV2155 negative polarity crystal detector and a suitable delay.

A filter was added to guard against the possibility of "moding". If the magnetron generated power at different frequencies, proper cancellation would not be achieved. By selecting manetrons and modulators the energy spread was reduced so that one pulse in 10^6 exceeded the mean level by 1.25dB. A further improvement to 0.5dB was obtained by using a servo-controlled stabilizer for the supply voltage. Previously a slight drop in supply voltage (240 to 230V) changed the shape of the generated pulse and introduced noticeable jitter in addition to varying the magnetron output level.

A sampling oscilloscope is necessary to view pulses of such short duration. A tracing of an oscilloscope photograph showing the leading and trailing-edge pulses resulting from cancellation is shown in Fig. 3 (top) and the effect of the p-i-n switch is shown middle. The bottom trace is the short pulse on a reduced time scale.

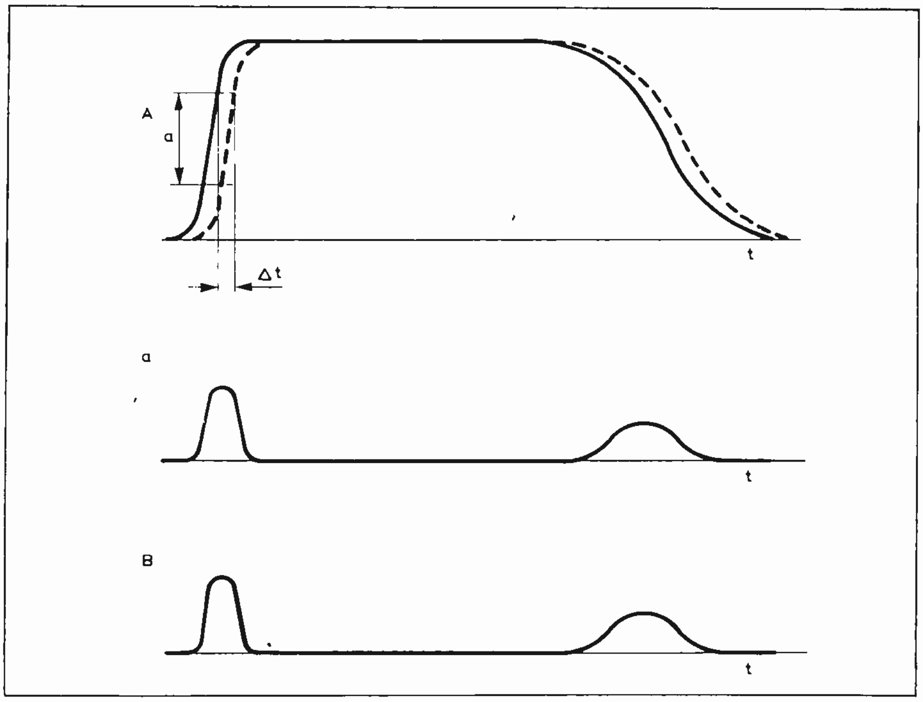

Fig. 2. *Diagrams show two r.f. pulses with a time difference Δt and the resulting leading and trailing-edge short pulses due to cancellation. (Diagrams show rectified envelopes of r.f. pulses.)*

Fig. 3. *Sampling oscilloscope displays showing leading and trailing-edge pulses resulting from cancellation (top, time scale 20ns/div), removal of trailing-edge pulse by p-i-n switch (middle trace, time scale 20ns/div), and the short pulse on expanded time scale (4ns/div). Diagrams show rectified envelopes of r.f. pulses.*

The short-pulse energy was measured as follows. The sampling oscilloscope was calibrated in amplitude using rectangular pulses of known duration together with an average power measurement using a thermistor bridge. The short pulse amplitude was then measured by means of this amplitude calibration. An accurate rotary-vane waveguide attenuator brought the short pulse amplitude on the oscilloscope to the reference level, thus eliminating any errors due to detector non-linearity. Amplitude was then calculated knowing the reference level power, and the number of dB difference in waveguide attenuation. The short pulse energy was then the product of short-pulse power and pulse width at half power (−3dB level).

The pulse generator had a useful output of 6 to 7 ns pulses with an energy of 1,000nJ and, on average, one pulse in 10^6 had an energy of 0.5dB above the mean. □

This article reflects a small part of the work that led to a degree thesis at Dundee University. Alan Hood studied for his M.Sc. part time whilst working with Ferranti Ltd on microwave radar system components. He became a part-time lecturer at Dundee College of Technology in electrical engineering and is now a lecturer at Kingsway Technical College, Dundee and a tutor/counsellor with the Open University.