$$W \geq \frac{U+V}{1+U\frac{V}{C^2}}$$

Project c+

Data comms beyond light speed

Research papers by their nature are difficult for the average layman to understand. Here in the *Elektor Electronics* laboratory between the odd cup of coffee we spend much time studying scientific reports. A recent paper by a Japanese research group caught our eye because we were able to replicate the effects described using a very simple circuit and the results are so profound that it could change forever the way we send data.

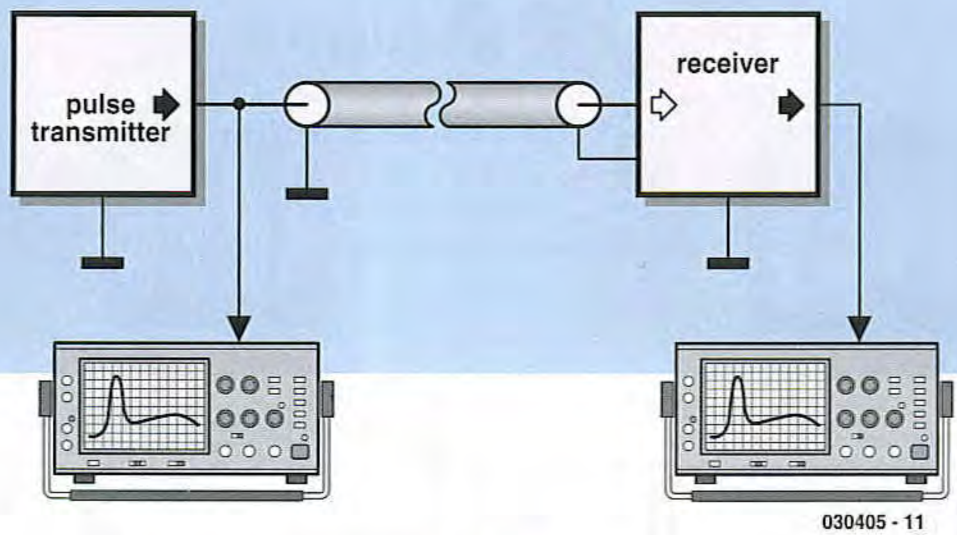


Figure 1. Experimental circuit for the Project c+.

The properties of light that most of you will be familiar with are that it travels in a straight line at a speed, *c*, of approximately 3×10^8 m/s. We should not forget to mention that this is only true when it is passing through a vacuum and not influenced by gravity. As soon as it enters another medium, light is slowed down and bent (refracted). In the latter part of 2003 M. D. Lukin and his colleagues at Harvard University announced in Nature [1] that they had successfully slowed down a pulse of light in a matrix of rubidium atoms such that it was stationary for a few hundred milliseconds before it was released and accelerated to regain light speed. The uses of this technology are manifold in the fields of quantum communications and photonics.

Drawing on these techniques a team of Japanese researchers have adapted the technology (termed *I-Ging*) to accelerate precise (low frequency) pulses of electromagnetic energy along transmission lines to achieve incredible propagation speeds.

Inverting causality?

The experimental set-up is shown in **Figure 1**. The pulse transmitter on the left of the diagram generates a signal pulse that is sent through the medium (either an optic fibre or simple cable) to the receiver circuit on the right hand side of the diagram. Two oscilloscopes are used to display the signal pulse when it is introduced to the medium and recovered by the receiver. The purpose of **Project c+** is to demonstrate that by careful matching of the pulse to the fundamental characteristics of the transmission medium it is possible to achieve vastly reduced propagation delays.

The breakthrough

It is often the case that a scientific breakthrough occurs by accident where unexpected or anomalous results suddenly cause the investigation to veer off in a totally different direction. The story of this breakthrough is a case in point, it seems as though during routine network testing one of the research team mistakenly entered a frequency range of mHz (yes, that's millihertz) rather than MHz (megahertz) into a programmable waveform generator. The resultant effect on the test circuit was truly bizarre and may have easily been dismissed or overlooked had the researcher been less observant.

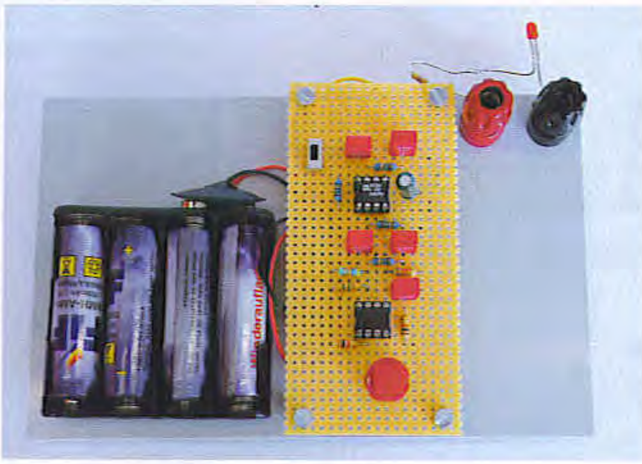
Normally in the field of high speed communications we are accustomed to propagation delays in the order of picoseconds or even femtoseconds but provided we use the correctly profiled pulse shape (a fundamental *I-Ging* pulse containing no higher order harmonics) coupled to a transmission medium originally intended for much higher frequency signals it seems as though it is possible to accelerate the pulse to such an extent that it undergoes localised temporal inversion in its passage through the medium and arrives much earlier than predicted (hence *c*+).

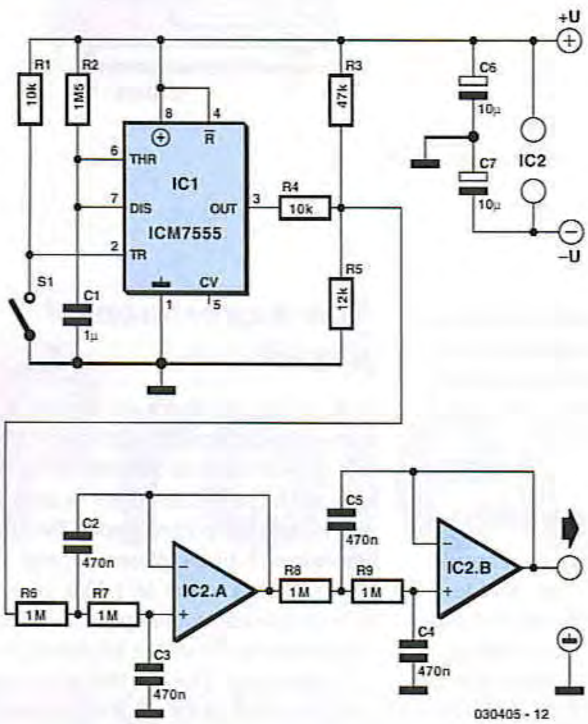
The experimental circuit

The pulse generator in **Figure 2** is quite straightforward and consists of a CMOS 555 timer IC together with two cascaded band-pass filters to produce the necessary pulse shape. The filter resistors are all 1% tolerance metal film types with a value of 1 MΩ (choose matched values where possible). Filter capacitors are low-loss foil types with 1% tolerance. The correct choice of components is critical to the success of the circuit, a fact to which any competent audio engineer will attest.

There are two possible power supply configurations for the circuit: either plus and minus 4.8 V consisting of eight NiMH AA type cells (if the TL082 op-amp is used) or a single-ended 4.8 V supply if a precision rail to rail op-amp like the OP290 is used. In this case the negative pole of the supply must be connected to the earth and all minus supply connections in the circuit diagram. To be scientifically rigorous the generator and receiver should be powered from separate power supplies to avoid cross coupling but a common supply will suffice for this experiment.

Once the circuit is completed the output waveform of the *I-Ging* generator can be observed on an oscilloscope. When S1 is pressed a transmission pulse similar to that shown in **Figure 3** will be generated and sent down the medium. Each square graticule represents 1 second.





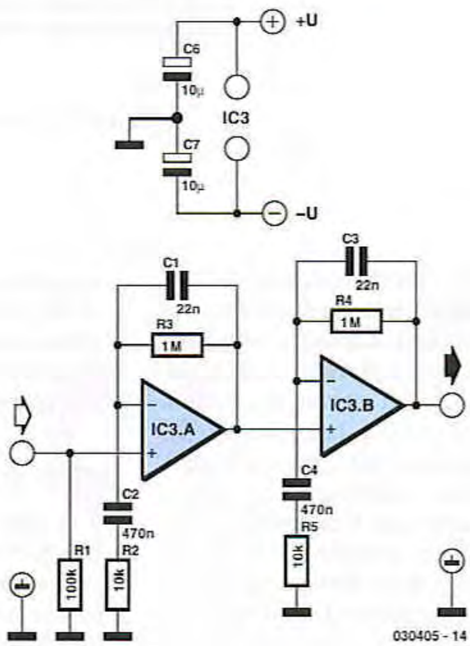


Figure 2. The I-Ging pulse generator uses high precision components.

Figure 4. The regeneration amplifier.

The medium

The choice of cable is vital in order to match the pulse profile to the characteristics of the transmission medium and thereby achieve the observed pulse acceleration. After much trial and error in the *Elektor Electronics* laboratory we concluded that a length of twisted-pair 100 Mbit/s Ethernet cable (CAT5) operated in the sub-hertz frequency range gave the most consistent results.

A cable length of 400 m was used in the prototype. In practice it is a good idea to cut it slightly longer so that it can be trimmed during testing to find its optimum length. The cable introduces a certain degree of attenuation to the low-frequency content of the pulse so the receiver circuit is provided with some amplification to compensate. The receiver circuit diagram is shown in **Figure 4** and uses a configuration similar to the transmitter. To operate reliably it is essential to ensure that the specified components are used throughout the circuit. The power supply can again either be single rail if you choose the OP290 opamp or split-rail for the TL082. Once the receiver has been carefully completed and checked we can begin with the experiment.

Back to reality

Figure 5 shows the test configuration for sending and measuring the high-speed pulses. With an oscilloscope connected to the transmitter output and another connected to the receiver output it can be clearly confirmed that when push button S1 is pressed, the transmitted pulse arrives at the receiver before it is detected as having left the transmitter! Even if you do not have an oscilloscope the effect is so pronounced that it can be demonstrated by substituting two simple LEDs at the measuring points and observing the events that occur when S1 is pressed. It is clearly observable that the receiver LED is lit slightly before the transmitter LED and then extinguishes before the transmitter LED! **Figure 6** shows the pulse waveforms as seen on a scope. It may be necessary to adjust the length of the cable slightly if the effect is not observed.

The revolution begins

The simple circuit described here replicates the findings of the original paper but only achieves a data rate of 0.5 b/s. To be truly useful this needs to be much faster, certainly in the region of Gb/s. To make the technology more practical a form of dynamically adaptive pulse shaping will also be necessary to compensate for the medium characteristics. Research into I-Ging is still in its infancy but these early results are so promising that we will undoubtedly see its adoption in more and more applications as the technology matures.

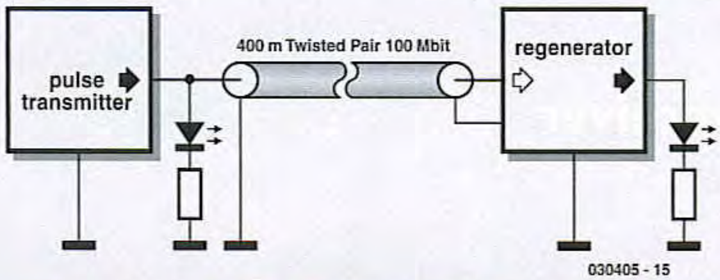


Figure 5. Test configuration with two LEDs to demonstrate the effect. A two channel scope can also be used in place of the LEDs.

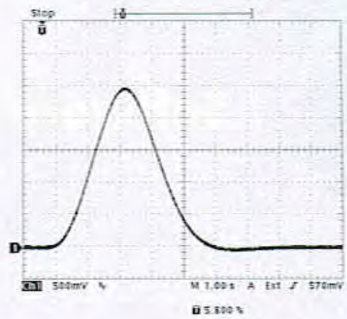


Figure 3. The transmission pulse.

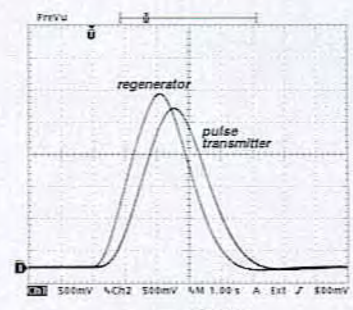


Figure 6. The impulse demonstrates localised temporal inversion.

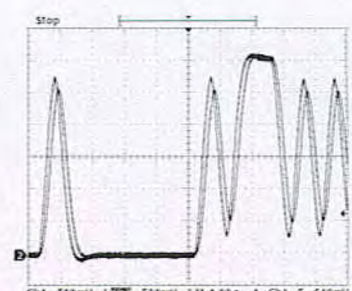


Figure 7. The technique applied to data transmission.

The principle of causality is a cornerstone of our interpretation of the physical world but the observed negative propagation delay of approximately 0.4 s through the transmission medium and receiver combination seems to conflict with our understanding of this principle and will no doubt set alarm bells ringing for many *Elektor Electronics* readers, theoreticians and scientists.

In practice this technology would be used to send a stream of data at incredibly high speed rather than just a single pulse. The circuit was modified to send a pseudo random data sequence and the results are shown in **Figure 7**. The received signal shows very low levels of distortion and noise and more importantly still exhibits identical negative propagation delay through the medium.

The circuit described here is quite simple and we feel that many sceptics amongst you will not be silenced until they have built the circuit for themselves and witnessed what must surely be a new dawn for communication science and computing.

Can you explain the c+ phenomenon? If so, let us know as soon as you can so we can revert to the subject in next month's issue.

(030405-1)

Reference

[1] http://lukin.physics.harvard.edu/Nature426_638.pdf