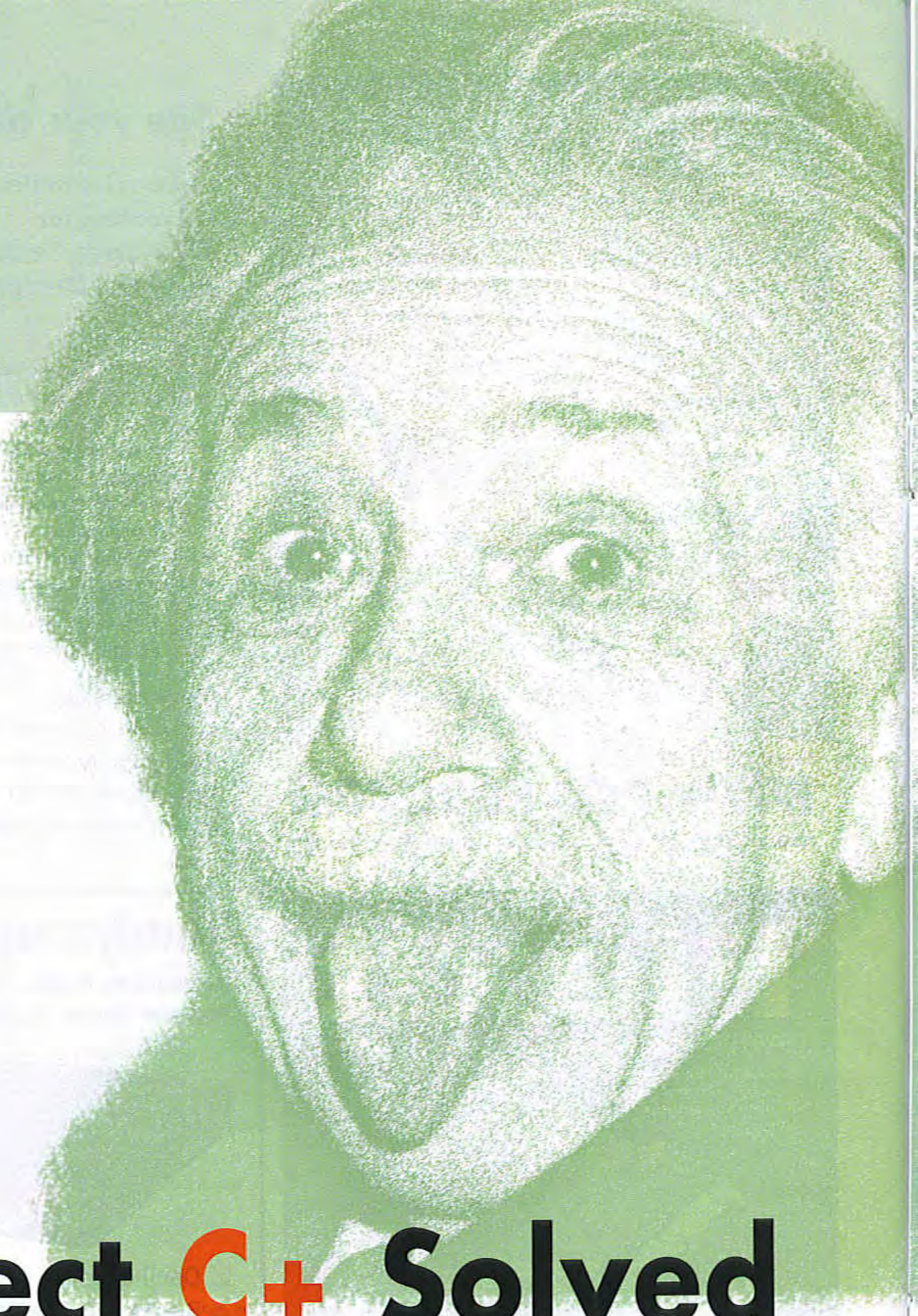

Prof. Martin Ohsmann

Project C+ Solved

The circuit described in the April 2004 edition of *Elektor Electronics* certainly gave rise to a lot of head scratching and raised eyebrows when it was shown to produce an output pulse ahead of the input pulse. Is it possible that such a simple circuit can turn the principle of causality on its head? Read on...

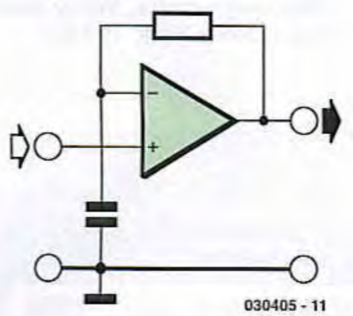

Figure 1. The lead filter with negative group delay.

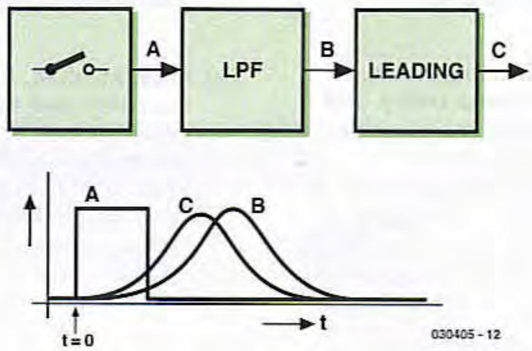

Figure 2. Block diagram of the experiment.

The idea for this article began when a student asked me if it was possible to build a filter that produced a 'negative group delay'. A quick trawl of the Internet (Google: 'negative group delay') soon gave some interesting hits. In particular Professor Kitano in Japan had published just such a circuit that apparently exhibits a negative group delay [1]. With kind permission from him we were able to use his ideas and circuit (slightly modified) in last month's article. So much for the background, now on to the details...

The concept of speed

If we consider the transmission of information in a communication channel, the first characteristic we need to look at is phase velocity. With a pure sinusoidal carrier wave this is equal to the propagation speed of any point (i.e., constant phase) on this wave. Without any form of modulation it is not possible to send information, so we can see that the phase velocity has no influence on the speed at which we can send information (i.e., the group velocity). Information can, for example, be transmitted on narrow-band signal pulses or envelopes and the speed of the envelope will be governed by the group velocity through the medium. Now back to the original question: if a circuit possessed a negative group delay this would imply that the information accelerates in the medium and travels backwards in time to arrive at the output before it was introduced at the input. This indeed is what appears to happen in our circuit.

This phenomenon has apparently been observed in the field of optics where anomalous dispersion (in a narrow spectrum) has seemingly produced a negative group delay and a refractive index smaller than 1. It is often the case that these effects occur when the circuit or medium is in resonance and an equivalent electrical experiment is described in a paper [2] which shows an output AM envelope leading the input signal thus yielding an apparent negative group delay.

It is easier to observe these effects by using a filter with negative group delay at low frequencies and DC. The circuit shown in **Figure 1** is a (low-pass) lead filter and produces the necessary effects. When a low frequency pulse from the generator described in the first part of this article is introduced to the lead filter, it should produce an output 'before' the pulse is introduced.

This basic idea has been perfected by Mr. Kitano [1] in a circuit that maintains the pulse shape through the transmission medium and produces a negative propagation delay. The pulse envelope travels at the group velocity and the pulse appears at the output of the filter before the input signal!

Causality

Causality states that in our physical world the flow of events is always the same: first, cause, then effect. You are aware of pain in your thumb after you hit it with a hammer and not before the unfortunate accident. If this principle is universal, is it possible in our simple circuit that a signal arrives at the output of a filter before it was applied to the input? Clearly not. To understand what really is going on in the circuit we need to take a closer look. **Figure 2** shows a block diagram representing the main parts of the circuit. A rectangular pulse is generated when the switch is momentarily closed at t = 0. A low-pass Filter (LPF) is used next to filter out the high frequency components and produce a smoothed Gaussian impulse at B. The pulse is now introduced to the medium and recovered by the lead filter to produce the output pulse C. The recovered pulse is amplified to produce the output pulse C so that its shape is similar to the input pulse.

The circuit doubles-up the pulse shaping and lead-filter stages to optimise the effect. Additional components in the Lead Filter help reduce noise in the circuit. The more observant among you will have noticed that the output pulse rises more quickly than the input pulse. It was found to be impractical to increase 'negative group delay' effect further by adding more lead filters. So there really is nothing unusual about the circuit, the effect is produced using just conventional components. The need for 400 m of cable was also something of a red herring.

The circuit demonstrates that in this case the group velocity is not relevant to the (negative) time difference

Literature

[1] M. Kitano, T. Nakanishi,K.Sugiyama, Negative Group Delay and Superluminal Propagation: An Electronic Circuit Approach, IEEE Journal of Selected Topics in Quantum Electronics, Jan/Feb 2003 (check the Internet).

[2] M.W. Mitchell, R.Y. Chiao, Causality and negative group delays in a simple bandpass amplifier, Am. J. Phys. 66(1), January 1998 (also on the Internet).

[3] J.DF. Jackson, Classical Electrodynamics, Wiley and Sons, New York 1975.

observed between the input and output pulses, here the **front velocity** (the propagation speed of an abrupt change or **front**) of the system is more important.

The effects produced here are still the subject of hot debate on the Internet but in any case you will no doubt be pleased that causality is still intact (at least for the time being) and this experiment underlines how careful you need to be when interpreting test results especially in systems using slow pulses. A similar phenomenon to that shown here occurs with a Mach Zehnder interferometer (no, honest), where light pulses appear to arrive 'too early'. For more information on this subject refer to [2]. If you are still curious about propagation speeds and anomalous dispersion then the classic work by Jackson [3] should fill in any gaps.

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