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A REMOTE TONE BURST PULSER DESIGN FOR AUTOMATED ULTRASONIC SCANNING SYSTEMS

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ABSTRACT

In this work, a programmable remote ultrasonic tone burst pulser circuit design and implementation for Automated Water Squirting Ultrasonic Scanning Systems (AWSUSS) are presented. This pulser can be configured by a PC over RS422 communication interface thus parameters such as pulse frequency, pulse repetition frequency (PRF), number of pulses in a burst, and pulse type (Positive/Negative Squared Wave or Bipolar) are set by user. High-voltage tone burst pulser can be adjusted between ±150 V in 300 V range. Hardware design of the pulser was made by using a Microsemi DRF1400 Class D half bridge MOSFET. Proposed pulser can excite piezoelectric ultrasonic transducers in the range of 0.5 to 15 MHz. The pulser output can provide 300 Vpp pulses with less than 0.5 Vpp ripple during the operation under load while rise time is less than 16 nS. The remote pulser was used with Mistras AD IPR 1210 digitizer board and successful C-Scan ultrasonic inspection results of aircraft composite parts are reported in this work.

Keywords*: High Voltage Power Supply, Pulse Generator, Ultrasonic, Transducer.*

OTOMATİK ULTRASONİK TARAMA TEZGÂHLARI İÇİN TON VURU ÜRETECİ TASARIMI

ÖZET

Bu çalışmada su şemsiyeli ultrasonik tarama sistemlerinde kullanılmak üzere tasarlanmış bir harici vuru üreteci devresi tasarımı ve entegrasyonu sunulmuştur. Bu vuru üreteci RS422 iletişim kanalı üzerinden bir PC yardımı ile kontrol edilebilir. Vuru frekansı, vuru tekrar frekansı, bir darbe katarı içindeki vuru sayısı ve vuru tipi (Pozitif/Negatif Kare Dalga veya Çift Kutuplu) kullanıcı tarafından ayarlanabilir. Vuru üreteci voltajı ±150 V arasında ve 300 V sahasında değiştirilebilir. Devre gerçekleştirmesi Microsemi firması tarafından üretilen DRF1400 serisi D Sınıfı yarım köprü MOSFET ile gerçekleştirilmiştir. Vuru üreteci 0.5 ile 15 MHz frekans sahasındaki piezoelektrik ultrasonik çevirgeçleri sürmek üzere tasarlanmıştır. Vuru üreteci çıkışı 300 V seviyesinde çıkış verirken yük altında 0.5 Vpp değerinden daha az salınım yapmaktadır ve çıkışı 16 nS'den daha kısa bir sürede 0'dan 150V'a yükselmektedir. Bu harici vuru üreteci Mistras firmasına ait AD IPR 1210 sayısallaştırıcı kartı ile birlikte kullanılmış ve kompozit uçak parçalarının, bu çalışmada tasarlanan vuru üreteci kullanılarak yapılan C Tarama muayenesinin başarılı sonuçları raporlanmıştır.

Anahtar Kelimeler: *Yüksek Voltajlı Güç Kaynağı, Vuru Üreteci, Ultrasonik, Çevirgeç.*

1. INTRODUCTION

In the field of NonDestructive Testing (NDT) Ultrasonic Test (UT) is one of the most preferred inspection techniques because of safety, reliability and operation costs [1]. UT has a wide application area in industry such as inspection in production line, quality control process, periodical maintenances for metals and composite materials [2]. Aerospace industry is an important costumer for UT systems. Increasing composite material usage in aerospace vehicles makes this market more attractive than ever before. Since inspected materials in aerospace industry are usually big in dimensions, automated UT systems are preferred for inspection. Ultrasonic signal acquisition in giant automated scanning system is usually made with PCI-Plug ultrasonic cards [3]. This requires using long coaxial signal cables from PC to ultrasonic transducers of UT system. Long cables cause attenuation and deterioration on ultrasonic signal. For

these reasons, extra circuits such as amplifier and filter circuits must be used between PC and ultrasonic transducers [4].

UT on aerospace composites are made by a couple of ultrasonic piezoelectric transducers excited with high voltage (>100 V) electric pulses with a frequency range generally changes from 1 to 5 MHz according to thickness of the inspected material. Therefore, one of the most critical part of UT system is pulse generator (pulser) unit [5]. Airplanes' composite parts can be very big in size. Hence, military and commercial airplane composite manufacturing plants usually utilize giant Automated Water Squirting Ultrasonic Scanning Systems (AWSUSS) as gantry (bridge or towers) or robot forms and the dimensions of the AWSUSS can be more than 10 meters in length. UT inspection with water squired system can be performed either Through Transmission (TT) or Pulsed Echo (PE) techniques. However, TT is the most preferred one in automated systems because of its signal acquisition success [6]. Ultrasonic waves are produced by a sender piezoelectric transducer and travel over inspected composite material from sender to receiver within a water medium. Ultrasonic waves are attenuated during their travel and those weakened signals. The produced signal on the receiver transducer has to be transmitted to the digitizer board that is generally a PCI-Plug device mounted on a PC, with hundred-meter coaxial cable that will lower the signal extra. Since the single amplitude is very low, at least a pre amplifier with band-pass filter is needed in receiver side to amplify the received signal in order to tolerate these amplitude loses [7]. Designed automated UT inspection system's operation flow in TT mode is given as Figure 1.

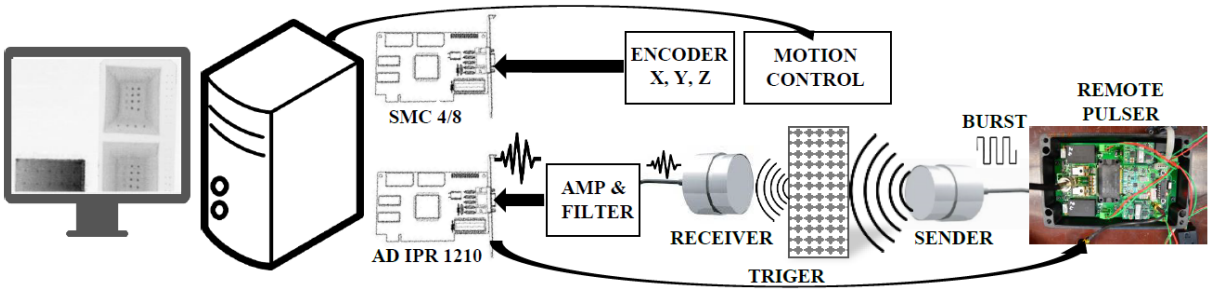


Figure 1. System operation flow in TT inspection mode.

Pulser unit consists of two main parts that are high voltage DC power supply and switching circuit. Since ultrasonic piezoelectric transducers behave as capacitive load, switching circuit must be designed using with MOSFETs. Because amplifiers such as OPMAPs do not have high enough slew rate to drive the capacitive loads with high voltages [8]. UT device manufacturers use MOSFET drivers in their products. Creating a high voltage DC power supply is not a complicated task however bipolar and adjustable high voltage DC power supply design is a complex task because of the design limitations of symmetric high voltage power supply [9]. In UT device market there are many UT boards exist for AWSUSS with different properties. Available PCI plug UT pulser/receiver devices are summarized in Table 1. It can be seen in the table, pulser output types are different in terms of number of channel and pulse type.

Table 1. A comparison chart for commercially available PCI plug ultrasonic pulser/receiver boards.

Brand	Model	Comm.	Channel	Pulse Type
US ULTRATEC	DSP UT 5000 [10]	PCI	Two	Positive/Negative Square and Tone Burst
MATEC	TB1000 [11]	PCI	Two	Gated Sinusoidal and Tone Burst
SOCOMATE	USPC7100 [12]	PCI	Single	Negative Square Wave
DR HILLGER	HILL-SCAN 3010 [13]	PCI	Single	Negative Spike
QNET	PCUS 11 [14]	PCI	Single	Negative Square Wave
OPTEL	OPCARD 2.2 [15]	PCI	Single	Positive Square Wave
SOFRATEST	SFT4001H [16]	PCI	Two	Negative Square Wave
MISTRAS	AD IPR 1210 [17]	PCI	Single	Negative Spike
JSR ULTRASONIC	PRC50 [18]	PCI	Single	Negative Spike

Spike pulse performance is very good with PE inspection of thin composite materials at higher frequencies (such as 5 MHz). Aircraft composites can be classified in two major groups as lamina and sandwich composites. Lamina composites are generally thinner than sandwich composites and spike pulse can produce reliable results both in PE and TT modes. However large aircraft parts such as fuselage, wings, flaps and etc. are hybrid parts and composed of both lamina and sandwich composites. Sandwich composites for example honeycomb core types are usually thicker and absorb acoustic energy [19]. UT on sandwich composite is usually performed with TT inspection mode. There are several reasons for this but

the most important one is the amount of acoustic energy that can be transferred to receiver transducer of TT mode. Spike pulse energy is not enough to inspect the attenuated materials. In order to increase penetration rate of ultrasonic waves, lower frequencies, such as 1 MHz, are used [20]. Traveled distance of ultrasonic waves also reduces wave's energy. When TT mode is chosen, then the traveled distance is decreased in half compare to PE mode. Because in TT mode there are two separated transducers as sender and receiver, on the other hand, in PE mode there is a one transducer once it produces ultrasonic signals and receives them back. This situation doubles the time of light of sound waves in PE mode.

Spike pulse is a single, short-duration, negative-polarized, and its energy less than squared pulses. Since attenuated materials absorb acoustic energy, more energy is needed to inspect these kind of materials. Increasing the number of pulses of a burst increases the acoustic energy transferred to the material [21].

In this work Mistras AD IPR 1210 pulser/receiver board was used with a ground-mounted 10-axis WSAUSS (Figure 2) in TAI (Turkish Aerospace Industries) facilities for C-Scan inspection of airplane composite parts. C-Scan inspection requires location of ultrasonic transducers therefore Mistras SMC 4/8 PCI Stepper Motor Indexer Board [22] was used to acquire position data. Since AD IPR 1210 produces only negative spike pulses UT inspection results with sandwich composites were not satisfactory and reliable neither PE nor TT modes.

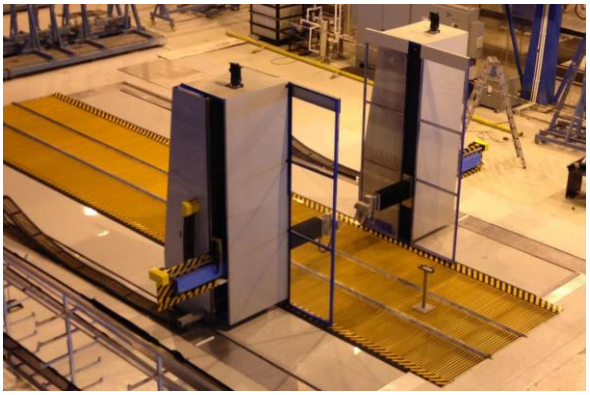


Figure 2. Ground mounted 10 axis WSAUSS.

AD IPR 1210 pulser output is given in Figure 2. This output was measured with Fluke 190-502 500 MHz ScopeMeter [23]. Setup parameters of pulser voltage, damping, load capacitance, pulse frequency and pulse width were chosen as -390 V, 2 KΩ, 820 pF, 1 MHz and 0.5 µS respectively. AD IPR 1210 board was not connected to piezoelectric transducer to eliminate the loading affect at the output. As seen in Figure 3, the measured voltage level of spike was – 506 V with a very short duration time without load, which is not good enough for UT inspection.

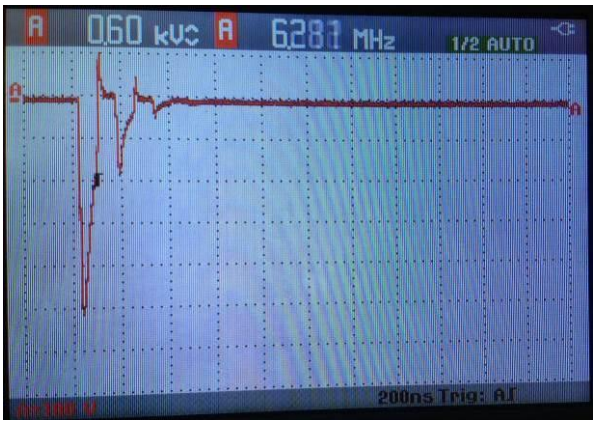


Figure 3. AD IPR 1210 pulser output.

Additionally, Olympus 1 MHz V314-SU Immersion Transducers [24] were used in UT inspection of honeycomb core sandwich composite.

2. HARDWARE DESIGN

Figure 4 shows block diagram of the remote tone burst pulser circuit. The remote pulser consists of mainly four parts, which are power supply unit, Micro Controller Unit (MCU), interface unit and MOSFET unit. Power supply unit produces fixed 5 V, adjustable ±150 V and floating 5 V above the +HV (Figure 5) from 24 V input voltage. MCU unit has a Microchip DSPIC30F3012 PIC microcontroller [25] working with 10 MHz system clock which controls the MOSFET driver by communicating with a remote PC over RS422 channel. Interface unit contains RS422 communication channel and isolated MOSFET driver circuitry. MOSFET unit contains a Microsemi DRF1400 D Class 30MHz half bridge power MOSFET [26].

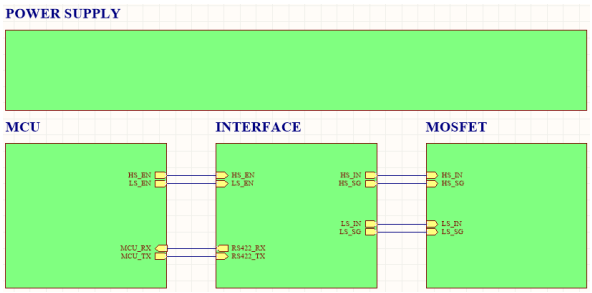


Figure 4. Remote pulser block diagram.

An ultrasonic piezoelectric transducer converts electrical (pulses) energy into mechanical (vibrations) energy and vice versa. There are different assumptions in literature and Butterworth-Van Dyke (BVD) equivalent circuit of a piezoelectric transducer is one of the most common used which is given in Figure 5 [27]. Understanding equivalent circuit is an important issue to design pulser circuit for required specifications. Here Cb is the capacitance between

piezoelectric transducers' two probes. R, L and Ca present the insertion losses and the series resonance.

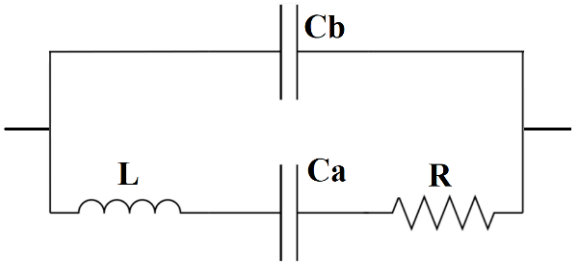


Figure 5. BVD equivalent circuit of a single piezoelectric transducer [27].

Squared wave peak to peak voltage value is dV, rise/fall time is dt and slope of rise/fall time is dV/dt. Bipolar pulses peak values are changed between positive and negative voltage levels around ground point. Positive squared wave rises from ground to +HV voltage, in contrast, negative squared wave falls from ground potential to –HV voltage level, which is given in Figure 6 [28].

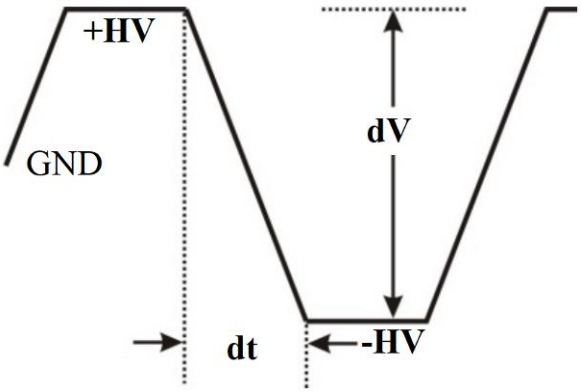


Figure 6. Squared pulse waveform and properties.

Olympus V314-SU piezoelectric transducers input capacitance is 4 nF and DRF1400 MOSFET output capacitance is 335 pF. The amount of current needed to drive a capacitive load with square pulses can be calculated by the following equation [28].

$$I = (C_{Load} + XpF)\frac{dV}{dt} \tag{1}$$

Olympus recommends short-duration, fast-rising, negative-spike-pulses going to 600 V to excite their transducers [29]. Allowed excitation pulse power is limited with 125 mW. When spike pulse energy is not enough to inspect attenuated materials then squared waves or tune burst pulsers are used. Because squared waves have much more pulse energy than short-duration spike pulses. Total power can be calculated with Equation 2.

$$P_{Total} = \frac{(DutyCycle)(V_{rms})^2 \cos(PhaseAngle)}{Z} \tag{2}$$

V314-SU 1 MHz transducer has 0.75 inch element diameter and driven by 300 V peak to peak (-150 V to 150 V), and has 50 Ω nominal input impedance.

$$V_{rms} = \frac{0.707 \times V_{pp}}{2} = \frac{0.707 \times 300}{2} = 106.05\,\text{V} \tag{3}$$

Duty cycle can be calculated by inserting $P_{Total} = 0.125$ mW into the equation 2 as below.

$$DutyCycle = \frac{Z \times P_{Total}}{(V_{rms})^2 \times \cos(PhaseAngle)} \tag{4}$$

If phase angle is assumed as -45°

$$DutyCycle = \frac{50 \times 0.125}{(106)^2 \times \cos(-45)} = \frac{6.25}{7943} = 0.78 \text{ mS}$$

This piezoelectric transducer can be driven for 780 µS in 1 S period of time. Number of pulses in a burst can be calculated with Equation 5. PRF is assumed as 78 Hz.

$$NumberofPulses = \frac{Frequency \times DutyCylce}{PRF}$$
$$NumberofPulses = \frac{1 \times 10^6 \times 780 \times 10^{-6}}{78} = 10 \tag{5}$$

When pulse repetition frequency is chosen 78, each burst can contain squared bipolar pulses up to ten. After determination of the all-important parameters of the pulses, to calculate the amount of current that is needed to excite ultrasonic piezoelectric probes, Equation 1 can be used. Here dV is 300 V and pulser reaches from 150 V to - 150 V within 32 nS (fall time).

$$I = (C_{Load} + XpF)\frac{dV}{dt} = \frac{\left(4 \times 10^{-9} + 335 \times 10^{-12}\right) \times 300}{32 \times 10^{-9}} \tag{6}$$

$I = 40.64$ A peak current is needed.

The amount of current is 40 A peak and fall time is 32 nS. OPAMPs or linear amplifiers are not capable to drive ultrasonic piezoelectric transducers at higher frequencies (MHz) and higher voltages with fast fall/rise time as bipolar tone burst driver [30]. However, MOSFET technology is capable to excite piezoelectric transducers. Figure 7 shows designed pulser PCB board. ElectroMagnetic Interference (EMI) compatibility of the pulser circuit was considered during PCB design. Since factories are very noisy places all necessary precaution were taken in order to improve conducted and radiated immunity of the remote pulser unit.

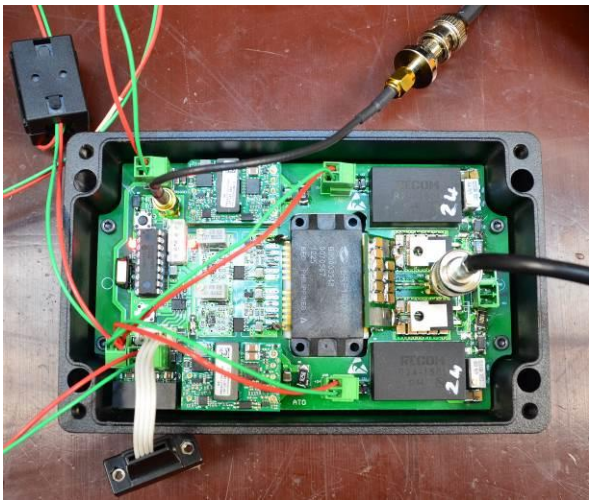


Figure 7. The remote pulser hardware.

The remote pulser can be programmed by RS422 interface and can work together AD IPR 1210 digitizer board thanks to external trigger port. When digitizer board trigs the remote pulser, the remote pulser generates squared tone burst pulses as it is programmed.

3. METHOD: ULTRASONIC INSPECTION WITH REMOTE PULSER

A powerful remote tone burst pulser was designed, implemented and operated successfully. Figure 8 shows pulser output that drives sender transducer (Yellow Ch1) and receiving transducer output (Green Ch2) in TT mode of UT testing. Number of the pulses of a burst are five and amplitude level is 300 Vpp with a less than 0.5 Vpp ripple under 4 nF capacitive load. As it seen form Ch2 receiving acoustic waves produce nearly 30 V amplitude on receiving ultrasonic transducer. This signal was achieved by directly coupling the sender and the receiver transducers to each other with water coupling medium. Inspected material, shown in Figure 9, causes a decrease on receiving signal amplitude dramatically. Because of this reason a logarithmic amplifier was connected to the receiver transducer, this logarithmic amplifier amplifies the signal and sent to digitizer board.

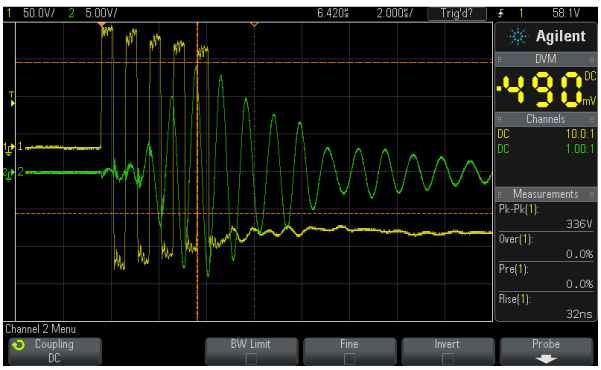


Figure 8. Remote tone burst pulser measured output.

WSAUSS was equipped with ultrasonic data acquisition, encoder reading and motion control systems. In order to test scanning system performance two special phantoms were inspected as shown in Figure 9. There are two nozzles which housing ultrasonic transducers and directing water jet for transferring ultrasonic waves in a water column. In this system, the left nozzle covers the sender transducer and the right one covers the receiver transducer. Water is a good medium and it helps to transfer much more acoustic energy to the receiver transducer by matching the acoustical impedances between the transducers and the inspected material. Inspected reference materials have different types of defects. These defects were not able to be detected with AD IPR 1210 spike pulser but the remote pulser energy is high enough to visualize all details of the defects as given in Figure 10.



Figure 9. Inspected reference materials are located between ultrasonic piezoelectric transducer couple.

An evaluation program was written in MATLAB environment in order to visualize inspection results as shown in Figure 10. Here the speed of AWSUSS was 7 m/min and the distance between transducers was 23 cm. The reason of slow scanning speed is small scanning area as 500×650 mm. Scanning resolution is 1 mm in horizontal and vertical axis.

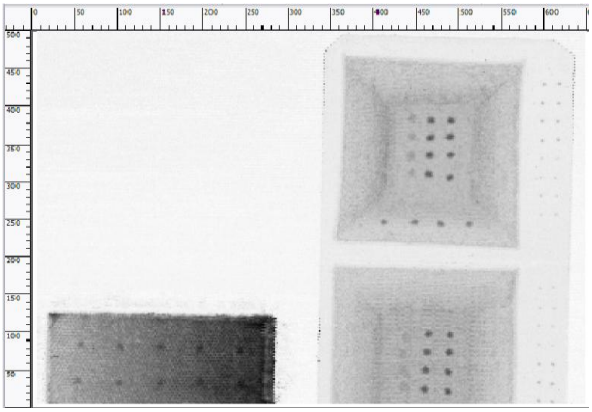


Figure 10. Screenshot of visualization interface written in MATLAB.

5. CONCLUSIONS

In this work a powerful programmable remote tone burst pulser was designed in order to make UT inspection of attenuative and thick materials using with commercially available ultrasonic digitizer units. There are some remote pulser units either in literature or market however available solutions have some limitations. They can produce squared or bipolar pulses by triggering a digitizer unit. However, their pulse amplitudes and frequencies are fixed or can be adjusted with potentiometers/trimpots integrated on device. To the best of our knowledge the number of pulses and pulse widths of available remote pulsers cannot be changed. Proposed pulser unit is controlled over RS422 and pulser voltage, frequency, PRF, number of pulses in a burst, pulse durations or polarizations can be programmed. These properties make proposed pulser unique in the literature and give ability to inspector use the pulser in variety of materials. This pulser unit is very convenient for upgrading existing UT inspection systems in plants.

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VITAE

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