THE FREQUENCY COMPENSATED 1000:1 RATIO EHT PROBE FOR IGNITION INVESTIGATIONS IN AVIATION & AUTOMOTIVE SPARK GENERATING SYSTEMS.

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Background:

Peak voltages from ignition coil secondary windings are typically in the range of 10kV to 30kV but can be higher and can reach in excess of 50kV under some circumstances.

These high voltages occur for a very brief time across a spark plug's terminals prior to spark ionisation or under any test condition when the spark plug is not used or not connected to the spark generating system's output. This "open circuit" coil secondary voltage value is an important ignition system parameter. The rate that the voltage increases with time is another important parameter. A fast rise time to the spark ionisation voltage is thought to be beneficial in overcoming the ohmic resistance of fouled spark plugs because less energy is dissipated there due to a shorter time interval prior to spark ionization.

In addition, a certain voltage threshold is always required to initiate spark ionisation (the spark's early phase known as phase 1). This voltage depends on the spark plug's gap and the composition of the gases and the gas pressure and temperature between the gap. During the spark's burn time however (phase 2), the spark plasma has a low impedance and the spark gap voltage is relatively low, only 30V with some aviation spark lugs and around 1000V for a typical automotive spark plug. A typical automotive spark plug has a gap voltage of around 600V on a free air test for example.

The high initial pre-spark ionization peak voltage or the "open circuit" output voltage of the spark generating system under test can only be measured by an especially made probe with a flat frequency response and also possessing the ability to avoid corona discharge which is very problematic with potentials over 30kV.

The photo below shows the custom built 1000:1 probe for this application:

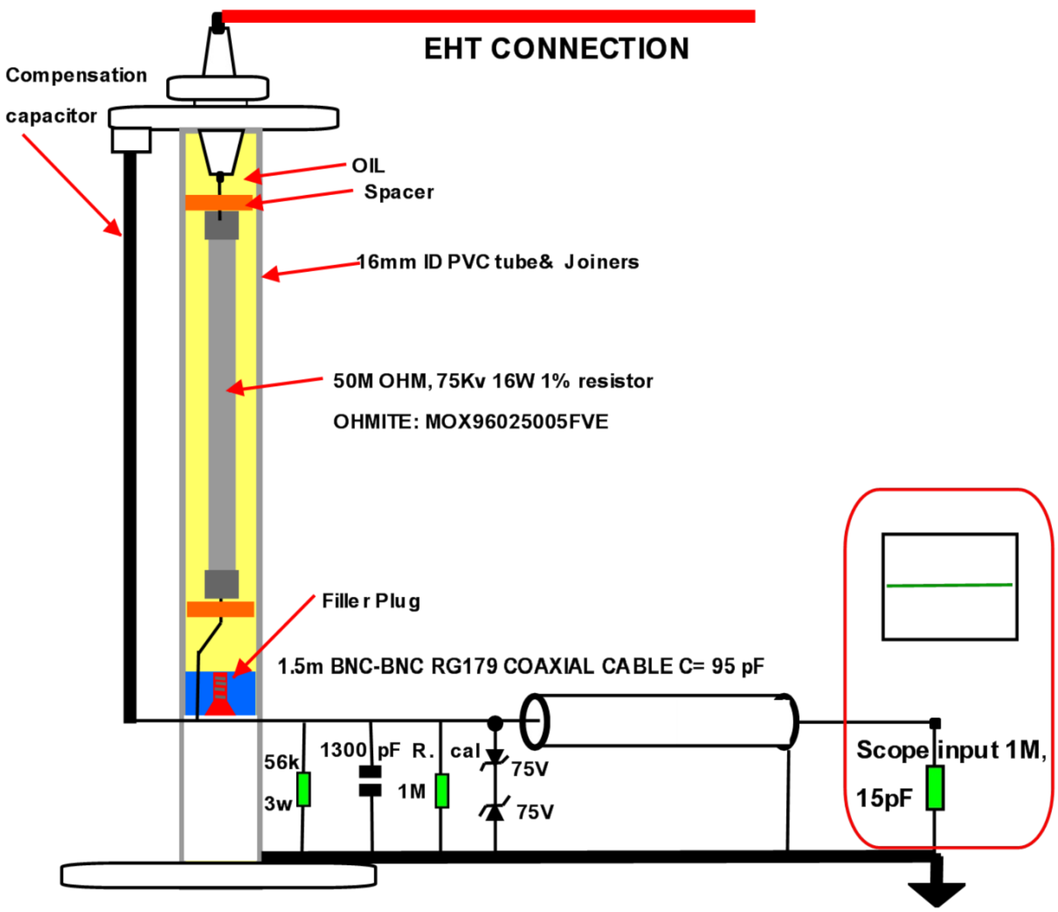
Therefore, the technical problem becomes how to accurately scale down a typical 30kV voltage to the input of a recording device such as an oscilloscope which has a 1 Meg Ohm and 15pF input impedance while still maintaining a broad frequency response so that the recorded wave maintains its original shape and so the oscilloscope itself is not at risk of damage.

While inexpensive high voltage or " EHT Probes" are generally available, for example to measure CRT anode voltages in this range, they are often for measuring static DC voltages. These give falsely very low readings on fast rise time voltages where the rise times are in the few micro seconds range and the high order Fourier components can be in the 100KHz to 1MHz range (see notes on square wave tests below).

High voltage compensated probes which can handle 40kV are available, but they are expensive and on some tests could be pushed passed their maximum ratings. In addition the probe tips do not easily interface with insulated spark plug connectors which are the best way to link up circuits running at these high voltages.

Also it is necessary to have a probe where its total load resistance is at least 50M ohms so there is little loading of the system being tested, or at worst case 1000 Ohms/volt for a 50kV test. A 200M Ohm load is also feasible yielding a 4000 Ohm/volt load, however the higher the resistance, then additional low pass filtering effects occur due to distributed capacity and the high frequency compensation becomes a little more difficult. Very high value series resistance creates a low pass filter (LPF) effect because even one pF or less of stray capacitance creates a significant low pass filter. For example with 100M Ohms and only 1pF stray capacity the filter created rolls off with a – 3dB point of only 1.6KHz.

The circuit below show the schematic of the probe in the photo above:



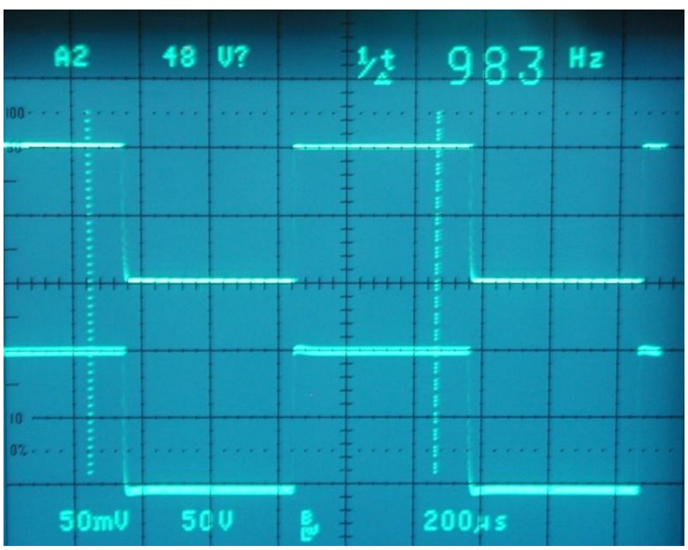
A spark plug was used as a feed in element by trimming the metal part a away. Bramite (similar to Garolite) was used as insulating material along with PVC tubing and parts of the assembly were glued with Torr Seal from Varian Vacuum Technologies. (This is a white epoxy resin which is also a very good insulator). The input capacitance of the probe is a little lower, at about 2 pF, compared to a spark plug which is typically around 8 to 10pF. The typical output capacitance of an automotive ignition coil is around 50pF and the HT wiring contributes another 10 pF or thereabouts.

As shown in the diagram above & photo the probe is constructed from PVC pipe. The central chamber housing the resistor is oil filled. (Transformer coil was scavenged from a Lucas ignition coil for this job). Without the dielectric oil, the corona discharge becomes very difficult at peak voltages over 30kV, the oil solves this problem.

CALIBRATING THE PROBE:

The DC calibration is easily set by small adjustments of the Cal resistor, but in general with the values shown and 2% resistors will be close enough for 1000:1 ratio when the probe output is plugged into the oscilloscope input. The DC & AC calibration was achieved using a Tektronix PG506 calibration generator. This unit can produce calibrated fast rise and high amplitude (100V) square waves over a range of frequencies from 100Hz to one MHz. The rise times are rapid and perfect for checking the frequency responses of amplifier or attenuator systems. The high amplitude output can rise 50V within 1uS with a 1kHz square wave output, so it is a very sharp rising edge square wave.

The AC calibration or square wave response is set by the 1300pF capacitor .This forms a divider with the brass rod which acts as an HF coupling capacitor distributed along the length of the resistor by proximity. The photo below shows the response with a 1kHz square wave prior to the DC fine calibration resistor being added to set the division ration to exactly 1000:1 with the probe plugged into the input of a Tek 2465B scope:

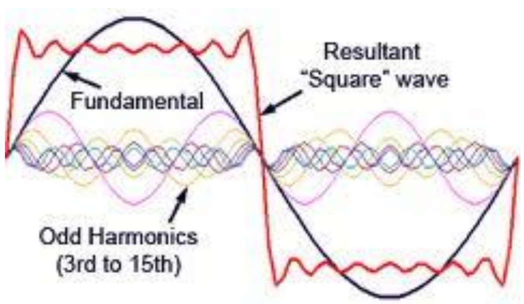


The upper trace is the input voltage which is a near 1kHz 100v peak to peak square wave from the PG506 generator. The lower trance is the output voltage which is close to 100mV pp. The Cal resistor was then added to gain the exact DC step-down ratio. (Without the compensation capacitor network consisting of the brass rod and 1300pF capacitor, the output waveform bears little resemblance to the input waveform and looks more like a sine wave due to the heavy low pass filtering effect of the 50M resistor and the stray and cable capacitances).On sine wave testing the probe has a flat response from DC to over 1.5MHz. The highest frequency of interest in an auto ignition system is about 300kHz.

Finally some protection 75V Zener diodes were added just in case there were any accidents with corona discharge which could harm the oscilloscope input amplifiers.

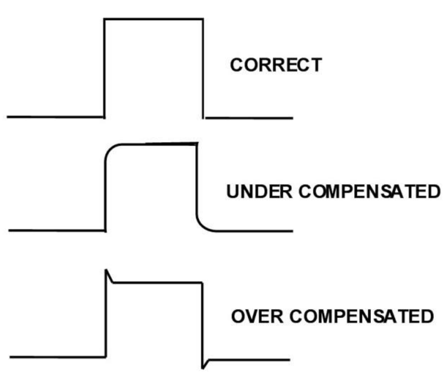
Some notes on square wave testing:

An amplifier or attenuator system could be checked for frequency response using a sine wave generator and sweeping the amplitude across a broad range of frequencies. However this requires a levelled generator and is very time consuming. According to the Fourier theorem a square wave or rectangular wave is composed of a fundamental frequency and a plethora of harmonic frequencies, the higher order ones being responsible for the rapid rise on the leading edge of the waveform. This is shown in the simplified diagram below:



Therefore if a square wave is passed through the system of amplifiers or attenuators, it is immediately obvious from its shape whether the frequency response across a broad range of frequencies is flat or not. If the HF response is limited the fast rising and falling edges are rolled off. If the rising and falling edges are peaked, then the HF response is excessive. If the flat top of the wave has distortions or bends or tilts then the medium frequency (MF) or LF responses are abnormal. (Most oscilloscopes for example have a calibration output voltage which is a square wave, so that the compensation capacitor on the x 10 probe being used can be set for a flat response).

The diagram below shows a rough diagram of square waves which are over or under compensated for high frequency response:



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