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Didactic device for the visualization of standing waves in electromagnetic resonators (SWV device)

Motivation:

The concept of wave propagation and the interaction of waves with matter is pivotal in many fields of physics and engineering (e. g. radio transmission, optics, sound propagation, transmission of information in waveguides…). Therefore wave propagation plays a central role in teaching physics, electrical engineering, information technology etc. from the undergraduate level (undergratuate engineering schools such as 'HTL') up to graduate schools and universities.

One of the most illustrative and therefore effective ways of teaching is just the visualization of the phenomena to be tought in a simple experiment. The direct visualization of the quantities to be observed has the big advantage of using the human eye as the 'sensor' and therefore creating the impression af an immediate understanding of the demonstrated effects. Such a demonstration or also a student's exeriment can be of considerable help for understanding the underlying, mathematically demanding concept. If the visualization hardware is big enough in size it can also be used in large classrooms and lecture halls, where the students have no possibility of directly interacting with the device.

One important phenomenon in wave propagation is that of reflexion and transmission at interfaces and the formation of standing waves (e. g. in electromagnetic devices such as transmission lines and resonators). This document describes a method vor visualizing such effects in transmission lines (TL), some electromagnetic resonators and strong microwave fields.

Basic idea: If the electric field around the wires of a transmission line or in a electromagnetic resonator is high enough it can induce luminescence in a gas of appropriately low pressure (gas discharge lamps) without the need of galvanically contacting the gas filling. This effect is well-known from experiments with Tesla-transformers in the near field of which fluorescent tubes shine brightly when just held in the hand of the experimenter. Contact is simply made through the capacitance formed by external electrodes (the hands) and the ionized gas inside the tube.

Part 1: Transmission lines

The same concept can be applied to a transmission line by bringing the latter into close contact with e. g. a fluorescent tube like e. g. in figs. 1 – 3. Then high frequency energy is fed to the line from a power amplifier which is capable of delivering enough power so as to rise the voltage in the voltage maxima of the TL above the threhold at which the gas will be ionized by the resulting electric field. Then the gas will luminesce more or less brightly according to the local field strenght and thereby visualize the voltage distribution on the line.

In fig. 1 the transmission line is built as a Lecher-line with two parallel wires going from the bottom of the vertically oriented TL to the top. Te TL is fed e. g. from the bottom and terminated at top. The TL is attached in straight form to the surface of a fluorescent tube.

This concept is most useful when it is possible to visualize at least half the spatial period of the voltage pattern, therefore the length of the TL must increase when lowering the frequency.

With 100 MHz the TL must measure at least 1.5 m in length, which may be somewhat inconvenient in smaller classrooms.

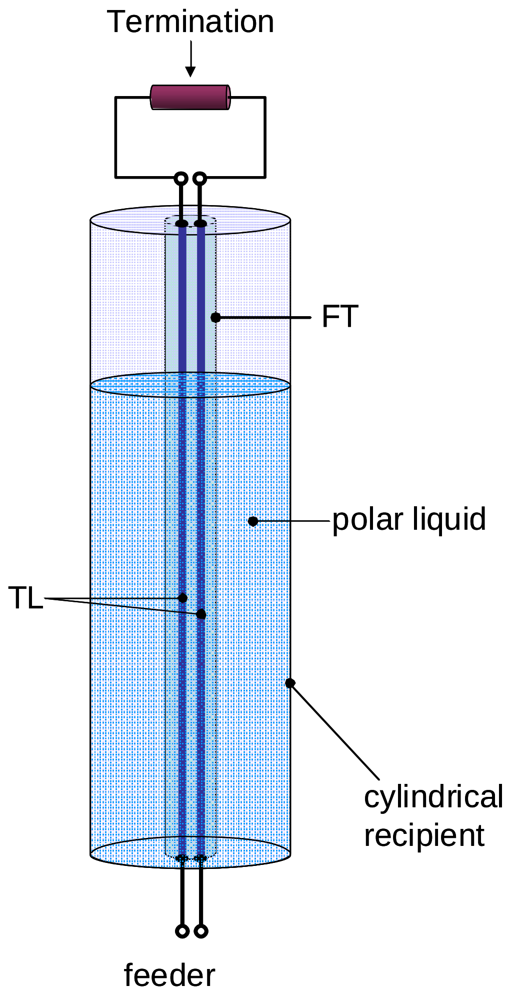

Fig. 1: SWV device with straight TL

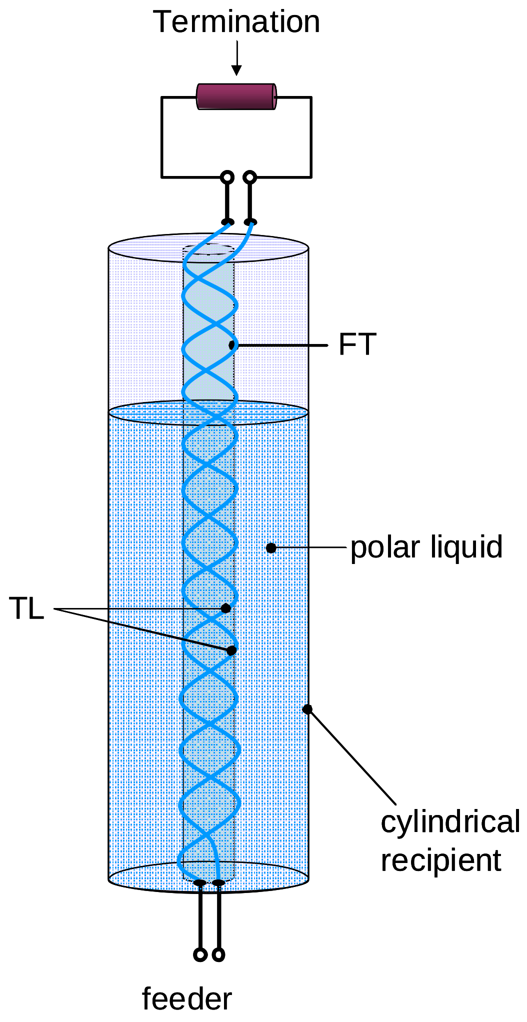

Fig. 2: SWV device with spiral TL

There are three convenient possibilities to 'shorten' the wavelength:

(1) rising the frequency. This is very effective but may cause additional complications due to the need of power amplifiers with very high cutoff frequencies and problems with electromagnetic compatibility issues.
(2) winding the TL around the tube as a spiral (see fig. 2) which allows for much shorter tubes (easily a factor of 3).
(3) increasing the relative permittivity of the dielectric near the wires of the TL. As shown both in fig 1 and 2 this can be achieved by embedding the tume plus TL in a transparent cylindrical recipient which allows a polar liquid to be filled in (e. g. glycerol, other alcohols or even highly purified water). With glycerol the wavelength can be shortened by a factor of up to approx. 6, depending on the exact geometry of the TL.

The whole configuration should be shielded by a wire grid which still allows for looking at the device but which shields the RF effectively.

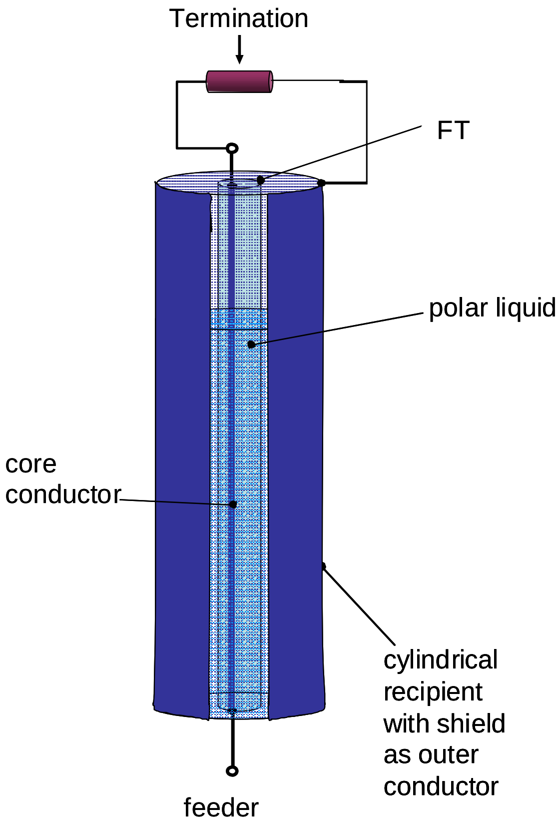

Fig. 3: SWV device with coaxial TL. The shield conductor has a vertical slit so as to leave a window to the FT.

Fig. 3 shows the same concept but in this case the TL is a coaxial type with just one single wire as core conductor on the fluorescent tube and a cylindrical metallic shield as outre conductor. The latter must have a slit through which the FT can be observed. Also here the core conductor can be wound around the tube in form of a spiral.

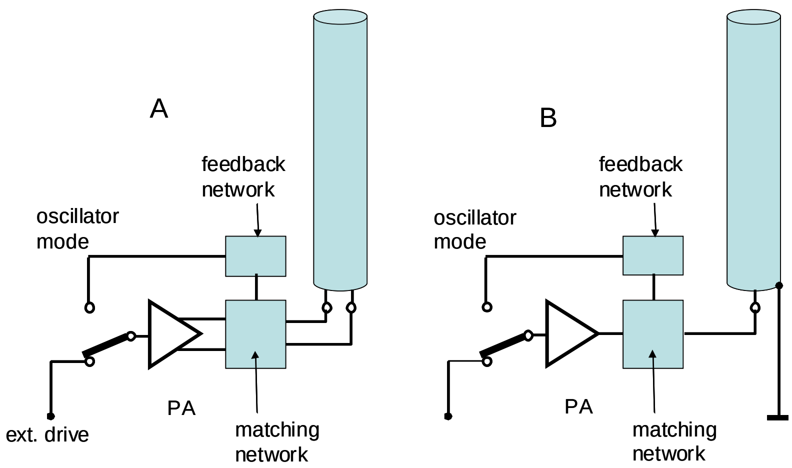

Fig. 4: Driving the SWV device. When the switch is in the lower position the TL is driven externally. With the switch in the upper porition the device works as an oscillator. Depending on the TL used the PA must either have a symmetrical output (A) or a single ended output (B). A matching network is needed so as to match the SWV terminal impedance with that of

the PA. In the oscillator mode also a feedback network is needed which provides the correct amplitude and phase condition for feedback.

The device is driven by a RF power amplifier (PA). A matching network is needed so as to match the SWV terminal impedance with that of the PA. The PA can either be fed from an external oscillator or by a portion of the voltage at the TL terminal by providing a feedback path so as to excite a self-sustained oscillation (see fig. 4). In the self-oscillating mode also a feedback network is needed which provides the correct amplitude and phase condition for feedback.

Aamong others the following phenomena can be demonstrated very easily:

(1) termination of a TL: When the TL is terminated on top the effect of the termination impedance on the wave pattern can be directly observed. Extreme cases like short circuit, open end and termination with the characteristic impedance can be easily characterized by observing the strength of the standing wave pattern on the fluorescent tube. In this way the concept of reflexion by the termination interface can be explained very effectively.

(2) reflexion on interfaces: When filling the TL with a polar liquid up to a certain level one can demonstrate how the jump of the dielectric constant produces reflexions and also a change of the wavelength. The fluorescence pattern will show a small spatial period in the liquid and a large period in the air space above the liquid.

(3) Avoiding reflexion with $\lambda/4$ transformers: When filling the cylinder with a hydrophilic polar liquid with relative permittivity ε_1 and then a hydrophobic, specifically lighter liquid with relative permittivity ε_2 = sqrt(ε_1) and a layer thickness of $\lambda/4$ then the disappearence of reflexions becomes visible.

Part 2: Resonator modes

When using the TL itself as feedback network, e. g. as a two-port, then the TL determines also the resonant frequency. As there exist multiple resonant frequencies the existence of different standing wave modes can be demonstrated. Just by changing the level of liquid the TL can be brought to resonance at different harmonics thus producing different light patterns. One possible example is shown schematically in fig. 6. To select a particular mode a feedback matching network is necessary which provides the correct resonance condition for the wanted mode at the input of the PA.

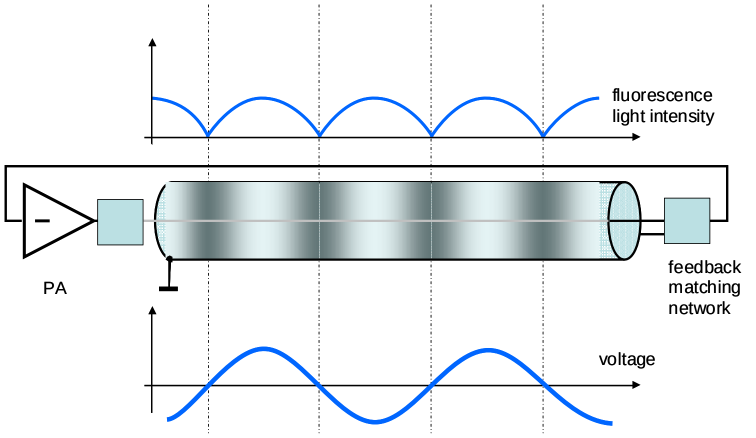

Fig. 6: Resonator with the TL as part of the feedback network. The resulting periodic voltage distribution leads to the shown intensity pattern of the fluorescent light.

Fig. 7 shows a photograph of a TL resonator with spiral Lecher line (according to fig. 2) filled with red stained glycerol oscillating at approx. 80 MHz. The appearance of the knots in the fluorescent pattern is clearly visible.

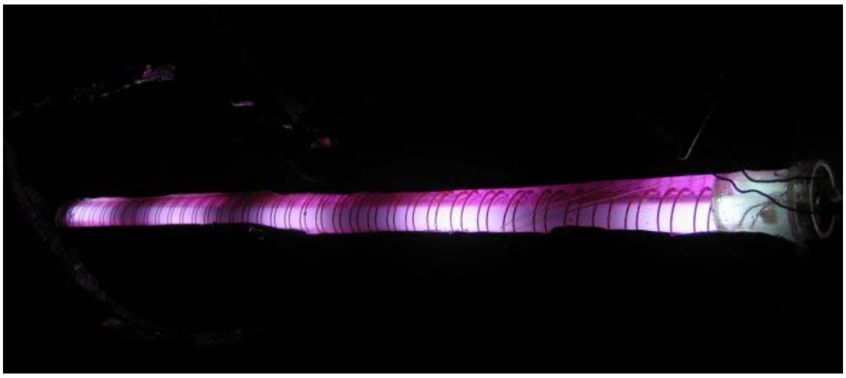
Fig. 7: SWV device with spiral lecher line and filled with glycerol stained with Fuchsine (rosaniline hydrochloride). The photograh is tilted 90° in order to save space.

This TL is being used in resonator mode as the local oscillator and tuning element in a radio receiver for show purposes. When changing the level of the fluid around the tube (glycerol), the eigenfrequency of the resonator changes and therefore the radio stations can be selected.