

frequencies at a sufficiently high voltage exhibit a greater tendency for arcing and for ionizing the air than power line frequency.

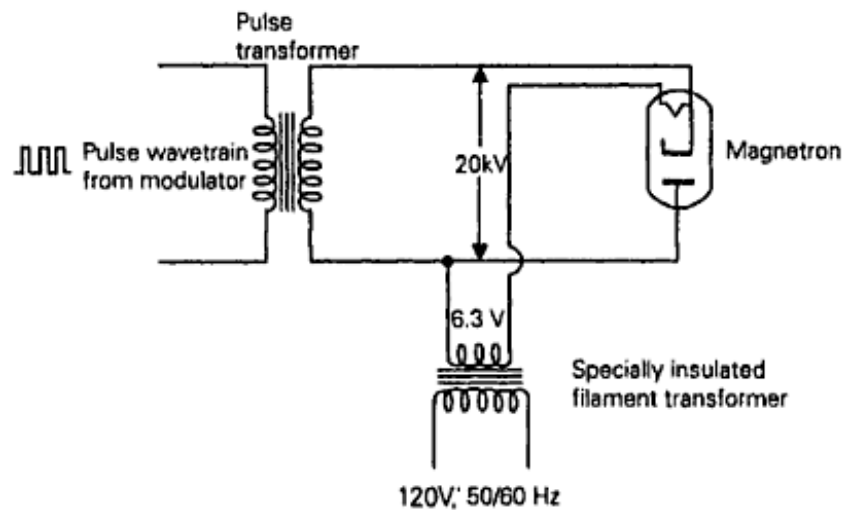
As can be seen, a step-up transformer is used to bring the 50/60 Hz a.c. up to sufficient potential to produce continuous actuation of a spark gap. Such a spark gap acts as a rapid-fire switch, interrupting the current twice per cycle. These current waveforms are very steep and are able to shock-excite the resonant circuit at a low radio frequency. The nice thing about this technique is that the hazardous low frequency a.c. is completely isolated from the output. An ordinary automobile spark plug suffices well for experimental purposes. Also, a Model-T type induction coil can be used to operate the spark plug. In any event, optimum operation depends upon energy back-up and on satisfying the resonance of the secondary output winding. This may call for a bit of 'cut and try' regarding both the high voltage capacitor and the design of the radio frequency output transformer.

### **Transformer technique for skirting high voltage problems**

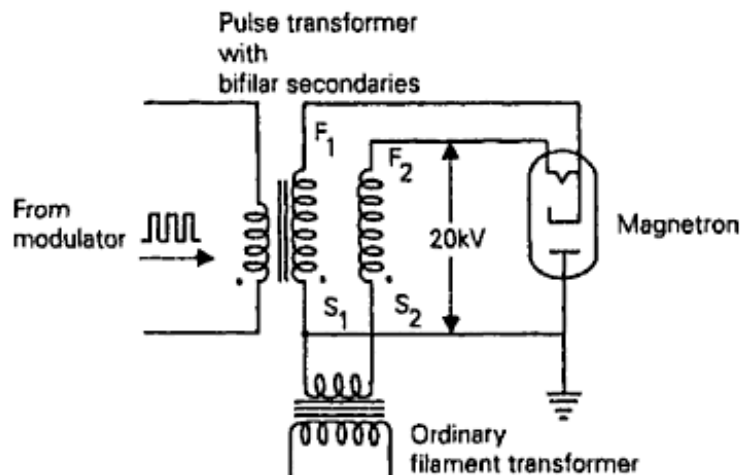
An interesting and useful transformer technique derives from radar technology. In many systems, it is desirable to deliver high voltage pulses to a magnetron which then becomes the source of the microwave radiation. The pulses are formed by a high power modulator at a selected pulse repetition rate and applied to the magnetron through a pulse transformer. As the magnetron has the format of a simple diode vacuum tube, the circuit implementation appears straightforward enough. Some practical problems loom up, however.

A more or less garden variety pulse transformer with an appropriate step-up ratio might be considered to supply the 20 kV or so pulses between the cathode and anode structure of the magnetron. Because of the magnetron's construction, it is common practice to apply negative-going pulses to the cathode filament terminal thereby enabling the anode structure together with the metal outer portion of the tube to be at ground potential. This is in the interests of safety and also obviates any need to insulate the magnetron from chassis metal. Insofar as concerns the operation of the tube, it 'sees' the required positive anode with respect to cathode polarity condition.

It can be seen by referring to Fig. 5.4 that the use of a two-winding pulse transformer would result in the filament being at a very high voltage with respect to ground. This, of course, would call for a large and costly filament transformer with a high voltage insulated secondary winding. Even if this 'brute force' technique were pursued, it is likely that there would be problems because of degradation of the pulse shape. Fortunately, a clever deployment of a three-winding pulse transformer can allow use of an ordinary filament transformer and at the same time enable the magnetron to operate with its anode structure at ground potential.



**Figure 5.4** 'Brute-force' circuitry for the operation of a magnetron. Although conceptually simple, this arrangement poses size, weight and cost problems; moreover, it would not be easy to preserve pulshape fidelity. The prime difficulty centres around the required high voltage insulation for the secondary winding of the filament transformer. Note that the pulse transformer secondary must be wound with wire capable of carrying the filament current of the magnetron.

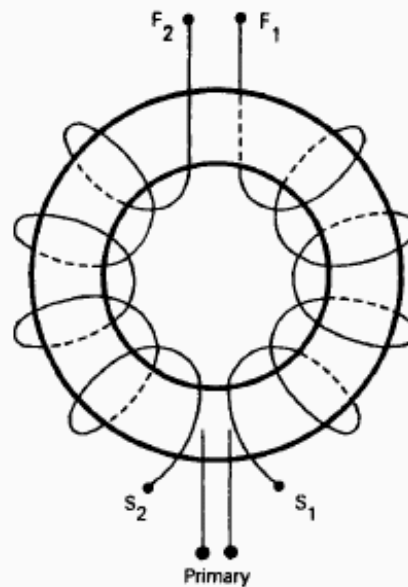


**Figure 5.5** Magnetron drive scheme using three-winding pulse transformer. The bifilar-wound secondaries remove the high voltage insulation requirement from the filament transformer. At the same time, the anode structure of the magnetron operates at ground potential.

A basic circuit of a three-winding pulse transformer used for driving a microwave magnetron is shown in Fig. 5.5. The two secondary windings are bifilar-wound with conductor sizes capable of carrying the magnetron filament current. Because these secondaries are identical, there is zero

potential between winding ends  $S_1$  and  $S_2$ . Similarly, there is zero potential between winding ends  $F_1$  and  $F_2$ . Note that the filament transformer 'sees' only ground or near ground potential. Therefore, no high voltage insulation is needed in the construction of the filament transformer. The anode structure of the magnetron is also at ground potential, but negatively polarized high voltage is applied to its cathode. This provides the same operation one would expect from a grounded cathode circuit with positive anode.

Overall, this transformer scheme leads to a system featuring safety, reliability, freedom from flash-overs and savings in cost and weight. This setup also proves helpful in attaining pulse integrity of the microwave bursts. The phasing-dots depicted for the three windings are proper for a modulator delivering positive-going pulses to the primary. For negatively-going modulation pulses, the phasing of the primary winding would be reversed. (Or, alternatively, the phasing of the two secondaries could be reversed *as a pair*.)



**Figure 5.6** An alternative winding format for a pulse transformer. Note that one secondary is wound in a clockwise direction, while its mate is wound in a counter clockwise direction. In operation, there is zero potential between  $F_2$  and  $F_1$ ; likewise, there is zero potential between  $S_2$  and  $S_1$ . This transformer provides the same features as the bifilar-wound type. The construction utilizes insulation between the core and the primary and then again between the primary and the secondaries.

An alternative winding format for a high voltage pulse transformer is shown in Fig. 5.6. The circuit connections remain the same as the transformer shown in Fig. 5.5 except that bifilar windings are not used for the secondaries. Instead, the secondaries comprise two separate windings.

These windings are wound in *opposite* directions. In Fig. 5.6 the primary winding is not seen because it is beneath the insulation that separates the primary from the secondaries. As with the bifilar type, this pulse transformer enables the anode structure of a magnetron to be at ground potential, with negatively polarized pulses applied to the cathode. This pulse transformer also frees the magnetron filament transformer from requiring high voltage insulation.

Both of these pulse transformers have been commonly made with step-up ratios of 4 or 5 to 1. The 20 kV, or so, developed in the secondaries has been found convenient for popular magnetrons. At the same time, 4 or 5 kV has been readily forthcoming from modulators feeding the primary. The experimenter may wish to incorporate these winding techniques in other high voltage applications such as photo-flash, laser or X-ray apparatus.

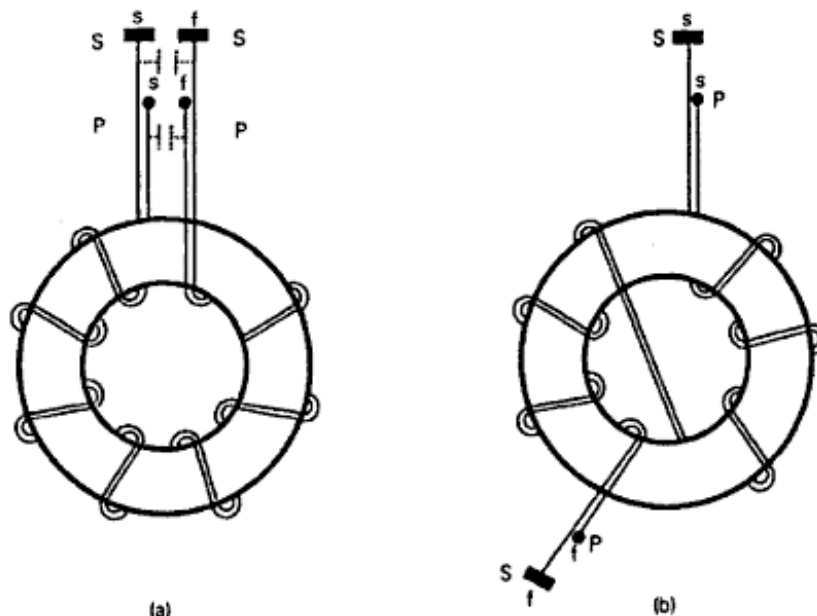
### A novel winding pattern

At high radio frequencies, certain departures from conventional practice often pay dividends in performance. Consider, for example, the two toroidal transformers shown in Fig. 5.7. Both have *bifilar* windings and both have one to one transformation ratios. The transformer at A may be said to be conventionally wound. It is good in many respects and will be found to have tight coupling and minimal leakage inductance. However, at high frequencies and high power levels, the capacitance between the physically-close leads can prove troublesome. Because the potential between the start and finish ends of the windings can be quite high, a very small capacitance is sufficient to produce an undesired resonance or to limit the tuning range. Even worse, there is the possibility of *voltage breakdown* and subsequent arcing.

Transformer B retains the good features of transformer A but the start and finish leads of the windings are physically far apart. The capacitive effect prevalent in transformer A is practically absent. Also, the likelihood of *arcing* is greatly reduced. As in transformer A, transformer B utilizes almost the entire core. The electromagnetic operation of the two transformers is practically identical, despite their different winding patterns.

Note what has been done in the winding of transformer B. Half of the winding is in one direction and half is in the opposite direction. Contrary to one's first thought, this does not bring about cancellation of the inductance. Indeed, overall inductance is about  $N^2$  or four times the inductance of each half-winding. This is due to the manner in which the series connection of the two half-windings is made. One might say that the phasing of the two half-windings is additive. If it is practically feasible, it is a good idea to have the interconnecting coil segment go right across the central region of the toroid as depicted in transformer B. Otherwise, there is nothing remarkable about this winding technique. At lower frequencies and/or power levels

it might show no advantages. Also, either type may prove best suited to a particular PC board layout.



**Figure 5.7** Winding techniques for high frequency toroidal transformers. Both are 1:1 bifilar-wound types, but with different winding patterns. (a) This is a conventional winding. Note the physical proximity of the start and finish leads in both primary and secondary windings. At high frequencies, these lead capacitances can exert strong effects on tuning, broadbanding and Q values. In transmitters, arc-overs can occur because the highest RF potentials exist between these leads. (b) With this super toroid winding pattern, the start and finish leads are far apart. End lead capacitance is reduced to a negligible level and voltage arc-over is no longer likely.

## Other techniques for high voltage transformation

Modern versions of the Tesla coil can make use of solid-state devices to generate the harmonic-rich pulse to excite the primary of the Tesla coil. (Of course, the so-called Tesla coil is actually an RF transformer.) Perhaps, however, most of these implementations more closely resemble the flyback circuits used to generate high voltage in television sets. It is not easy to replace a spark gap or a mechanical interruptor with a solid-state device when truly high voltage is required from the Tesla coil arrangement and attempts to do so remain on an experimental basis. The problems are with the rise and fall times of such devices as Triacs, SCRs, GTOs and IGBTs. Power MOSFETs are faster and lend themselves to easy paralleling.

A compromise can be made by using any of the above devices in conjunction with a step-up transformer to operate a spark gap. The only