

Crossed-Field Amplifiers: Theory of Operation

Communications & Power Industries

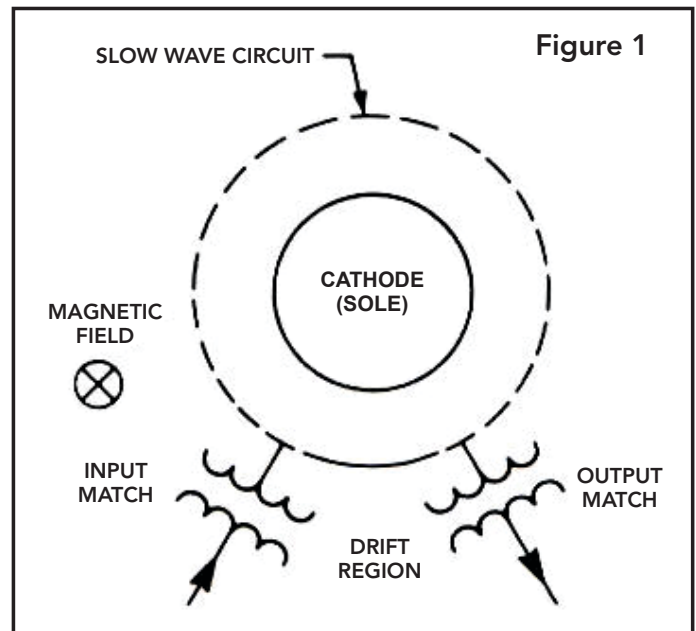
The CFA: Part Magnetron, Part TWT

The CFA is a vacuum electron device (VED) which might best be described as part magnetron and part TWT (Traveling Wave Tube). It is like a magnetron because it utilizes the same type of electronic interaction that a magnetron does (crossed electric and magnetic fields) and it derives many of the magnetron's characteristics as a result. It is like a TWT because electronic interaction is with a traveling wave and, of course, it is an amplifier (In a magnetron the electronic interaction is with a standing wave.) Power can be generated with high efficiency for the same reasons that a magnetron can do so. Power is also generated at voltage levels similar to those of a magnetron. In fact many CFA's look quite like a magnetron with the same form factor but with the addition of an input port.

The CFA derives its name from the fact that electronic interaction occurs in a region of crossed electric and magnetic fields, like the magnetron. This form of interaction distinguishes the CFA from the conventional TWT. Otherwise the CFA is made up of the same basic elements as a TWT. It has a slow wave circuit, an input-output system, and an electronic system.

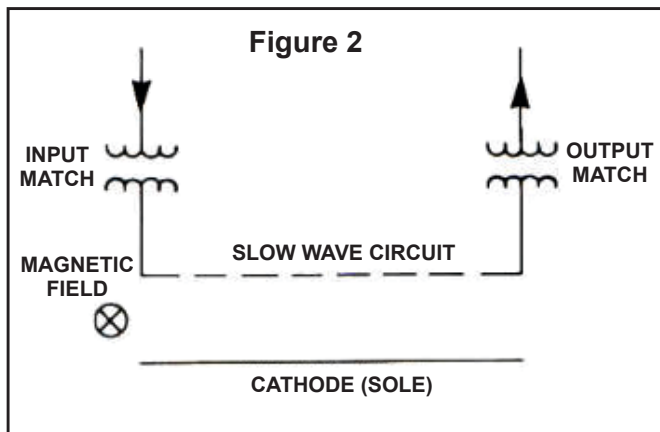
The slow wave circuit, or delay line as it is sometime called, is a periodic structure which has the circuit characteristics of a band pass filter. It must be capable of propagating RF energy over the frequency range of interest. It must at the same time provide fringing electric field lines with which electrons may interact. These fields must have a phase velocity approximately equal to the velocity of the electron stream.

The input-output system provides the impedance transformation between the RF transmission line system external to the amplifier and the slow wave circuit itself. These impedance transformations are called circuit matches and the bandwidth over which the VSWR of these matches can be kept low often determines the useful bandwidth of the CFA itself.



The electronic system generates electrons, confines them to the interaction area, and collects them when they are spent. Some cross-field amplifiers have electron guns which inject a beam of electrons into the interaction area. These amplifiers have been called injected beam amplifiers. Some amplifiers have a relatively large cathode which extends the entire length of the slow wave circuit. Electrons are generated along the entire length of the cathode. CFA's with this type of electron source are called distributed emission amplifiers.

Figure 1 provides a pictorial reference for the major CFA elements. The cathode is also called the sole and distributed emission amplifiers are sometimes referred to as emitting sole amplifiers. We shall use the words cathode and sole interchangeably. In Figure 2, the magnetic field is shown normal to the plane, and, during operation, the cathode will be negative with respect to the slow wave circuit. The magnetic field in this type of amplifier provides focusing forces for the electron stream and establishes the crossed-field which give the amplifier its desirable characteristics.



The distributed emission amplifier can be arranged in a number of ways. It can be made in either a linear or a circular format. Amplifiers made with the circular format may collect electrons at one end of the circuit, or the input and output sections may be brought close enough together so that electrons from the output are permitted to reenter the interaction area at the input. Reentrancy is employed in many amplifiers to enhance efficiency. When reentrancy is employed, however, it is possible that the reentering electrons are modulated with information which will subsequently be amplified. This is equivalent to providing an RF feedback and this feedback must be considered in determining the behavior of the amplifier. It is possible, however, to obtain reentrancy after demodulating the electron stream to eliminate the RF feedback.

Circuit Considerations

Historically the crossed-field amplifier principle was reduced to practice causing a backward wave circuit which was related to the magnetron circuit. The CFA was subsequently developed with a considerable support from the United States Government in that form to enable its application in radar systems. However, as will be seen in the following sections, the backward wave amplifier is a voltage tuned amplifier and the modulator voltage applied to it must be varied with frequency.

The forward wave amplifier on the other hand can realize its bandwidth at constant voltage like the TWT. For some applications the forward wave amplifier is more desirable, primarily because of modulator voltage considerations. At the present time, forward wave circuits which have been recently developed also offer the potential for greater bandwidth and are desirable for that reason.

Perhaps the most important element of a CFA is its slow wave circuit. In the CFA the slow wave circuit acts as the collector for the spent electron beam. Since CFA's are mostly used for high power applications, as opposed to small signal use, the slow wave circuit must be capable of dissipating the collected beam and transferring that energy to a heat sink.

- It must have the thermal capability to handle the required power dissipation.
- It must be capable of interacting efficiently with the electron stream. When it does it is said to have a high or a good interaction (or electronic) impedance.
- It must have dispersion characteristics sufficient to meet the bandwidth requirements of the application in which it is to be used.
- It must have properties which will permit an impedance transformation from the external transmission line system to the slow wave circuit. This transformation is called the circuit match or simply the match, and it must generally present to the external circuit a low VSWR over bandwidths which are large compared with the intended use bandwidth of the amplifier.
- It must be practical enough in its mechanical configuration to permit economic manufacture. In this sense it must also be capable of enduring system environmental conditions without detriment to its life or performance.

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This formidable list of boundary conditions has eliminated countless candidate circuits from use for the lack of one or more of the above prerequisites. In designing a new CFA for a system application therefore, the CFA designer may sometimes have to select a backward wave design because it may have the best circuit properties to meet the application, and the modulator may have to be designed or accommodate a backward wave device; or vice versa.

CPI's crossed-field amplifier (CFA's) product line has grown from a single concept to a large family of specifically designed amplifiers to meet the demanding requirements of pulsed high-power microwave transmitters. These devices are broadband, phase-stable microwave amplifiers used in coherent radar chains to efficiently generate very high peak output powers from relatively low input voltages which can be either applied to the cathode or an electrode similar to a TWTs cathode or grid pulsing, and in relatively small, lightweight packages.

These characteristics make CFAs particularly well suited for applications in which the transmitter must be either airborne, transportable, mobile, or portable.

CFA's are most often used as high power stages in master oscillator power-amplifier systems in which either frequency or phase information must be processed. They can also be used as simple power boosters, increasing the output of systems using magnetron oscillators.

With a history of producing high quality products, we can help you with crossed-field amplifiers and other radar products.

Contact us at BMDMarketing@cpii.com or call us at +1 (978) 922-6000.

