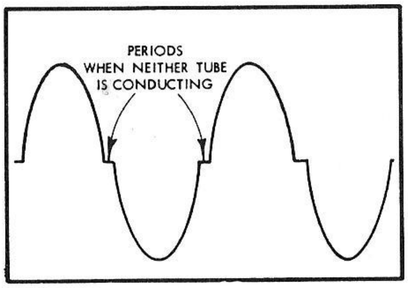

Fig. 2. Effect of overbias of class-B output tubes on waveform, showing crossover distortion.

quite low and large plate current excursions are only drawn when there is a large audio signal.

One of the problems of class-B operation is that incorrect bias can produce a form of distortion known as crossover distortion. This is due to the fact that transition from operation with one tube in one half cycle to the other tube during the other half cycle is not a smooth one. Crossover distortion shows up when the tubes are over-biased so there is a short period during which neither tube conducts current. This produces the waveform shown at *Fig.* 2.

In the early days of class-B operation much was said about this form of distortion, although it proved to be fairly easy to eliminate it by careful attention to bias arrangment. Some of the early class-B amplifiers, using transmitting type triodes with higher-than-normal plate-supply voltage, and extra high grid bias to match, were extremely efficient amplifiers in the higher wattage ratings. However, these amplifiers required extremely carefully designed drive as well as output transformers and a very well regulated plate supply. And the use of at least two transformers in the amplifier rendered them difficult for application of any degree of feedback, although the distortion of well-designed units was not more than that of well-designed class-A amplifiers of the period.

Improved tube techniques led to the use of pentodes and beam tetrodes more extensively as output tubes and circuits employing these could certainly deliver a bigger output more efficiently than their earlier predecessors. The one fly in the ointment about using beam tubes or pentodes in class-B operation proves to be the so-called "notch" distortion. This has been confused with crossover distortion but it is not the same thing. To some extent it is due to *similar* causes. Both distortions occur with tubes biased to operate in class-B.

While notch distortion proves almost impossible to avoid with pentode or beam tetrode output tubes, using normal transformer construction methods, it is not limited to these tube types. The lower plate resistance of the active tube in a push-pull triode circuit can contribute to the damping of the notch oscillation, which will not happen in the pentode circuit. The notch is excited by the sudden transfer of plate current from one half of the primary winding to the other, which triggers the resonance of the inactive winding, between its self-capacitance and the leakage inductance to other circuits, the secondary with its load, and the other half primary with its tube plate resistance.

The leakage inductance resonating with primary capacitance is damped only by the load resistance on the secondary (usually in between the two primaries) and by the plate resistance of the tubes in shunt with the effective resonant circuit. (*Fig.* 3). Plate resistance in a class-B circuit has a widely fluctuating value and in effect becomes almost open circuit at the crossover point, which stimulates the resonant circuit at the point where it is shock excited, especially when the exciting frequency becomes higher so as to approach more closely the resonant frequency.

For this reason, with even a moderately well-designed output transformer an amplifier employing pentodes or beam tetrodes in class-B push-pull would produce notch distortion at frequencies from 3000 cycles and up. It might be thought that over-all negative feedback would successfully eliminate the notch. But this does not occur, because the resonant frequency of the notch itself is also at a point where the feedback stability characteristic approaches its marginal condition. This means that, at best, the feedback will not improve the notch distortion and, at worst, it may considerably exaggerate it.

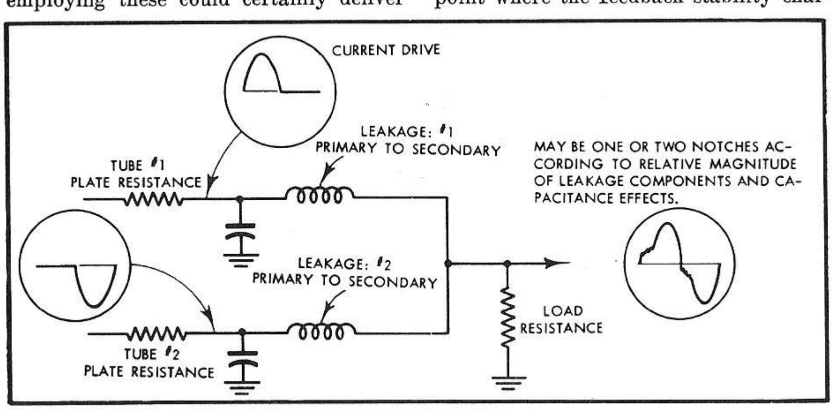

Fig. 3. Equivalent circuit of the quantities that cause "notch" distortion.

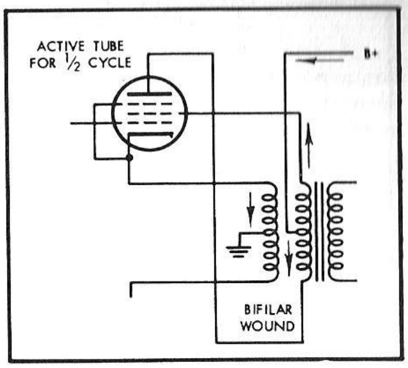

Fig. 4. How the bifilar-wound, unity-coupled circuit avoids the leakage flux transfer impulse that causes notch distortion. As plate current is equal to cathode current minus screen current, the effective current in both half-windings (regarding the bifilar pair as a unit) is always equal.

Eliminating Notch Distortion

How then can notch distortion be eliminated from this kind of output circuit? Two steps can be taken towards this end: (a) to bring the resonant circuit causing notch distortion nearer to critical damping; (b) to eliminate the excitation of the notch, due to the effective transfer of current suddenly from one winding to another.

Using straight pentode class-B operation, it might be possible to reduce primary capacitance by careful winding procedure. But this would merely push the notch frequency (i.e. its sharpness) out further, by raising the resonant frequency and correspondingly raising the point of marginal stability, where feedback ceases to help.

Reducing the leakage inductance, on the other hand, will increase the damping provided by the load. While this might conceivably eliminate notch distortion *into a resistance load,* it might reappear when a reactive speaker load is used.

Excitation of the notch occurs due to leakage inductance *between halves* of the primary, so that transfer of current from one half to the other induces a voltage kick in this inductance. Part of the solution, then, rests in eliminating or minimizing the leakage inductance between halves of the primary winding. Adequate results could probably be obtained by reducing the referred leakage inductance between primary halves to a small fraction—in the region of 1/10—of the leakage inductance between the primary and secondary. This method is necessary for a transformer intended for ultra-linear operation, if the ultra-linear