More Solid State Theory

UNDERSTANDING THE PUSH-PULL AMPLIFIER

WHY PUSH-PULL

When an RF carrier is amplified by a semi-conductor device (and this includes discrete transistors, FET's, chips and IC amps), not only is the signal amplified, but the semiconductor reacts as a (frequency) doubler or mixer.

For example, if we amplify a channel 2 visual carrier (55.25 MHz), at the output of the amplifier, we would measure not only the 55.25 MHz carrier, but we would also measure a *new* signal at 110.50 MHz, or twice the frequency of the input carrier. The new carrier or signal at 110.50 MHz is generated *within the semi-conductor* in the amplification process and it is called *second order distortion.*

Unfortunately, things get much worse when we amplify two carriers in the RF amplifier. If, in addition to our 55.25 MHz visual carrier, we also have a channel 4 visual carrier at 67.25 MHz, we would *expect* to have no fewer than 55.25 MHz, 67.25 MHz, 110.50 MHz (2 x 55.25), and 134.50 MHz (2 x 67.50) at the output of the amplifier. However, with two or more carriers *going into the amplifier,* we have *more* than just the two plus their 2x carriers *coming out.* Because in addition to frequency doubling the original input carriers (55.25 x 2 = 110.50; 67.25 x 2 = 134.50), *we also have sum and difference frequencies* present at the output of the RF amplifier. In this situation, we will also have 12 MHz (67.25 - 55.25), and 112.5 MHz (55.25 + 67.25).

Note there are six carriers present at the output, the original *two plus four more.* This is just an analysis of two visual carriers. A 12 channel system with 12 visual carriers, 12 aural carriers, 12 color sub-carriers, plus some quantity of FM band signals and a pilot carrier or two, starts to defy human computation!

Now naturally these undesired *second order distortion* carriers are never as strong coming out of our amplifier as our primary desired signals. But they are there, and if they were to happen to fall on or within a visual carrier signal region of a TV channel on the system, we would see some form of picture degradation on our desired pictures. (See *CATJ for May 1974,* Pages 24/25 for beat pattern effects.)

When the Federal Communications Commission first allocated the 12 VHF television channels we now function with, this potential problem was at least taken into consideration. Certainly not with CATV or line amplifiers in mind, but with direct transmitter radiation problems in mind. Consequently, low band channels were so grouped so that when we apply the "2x rule" to their primary frequencies, we find that 2x the primary frequency always falls someplace *above channel 6 but below channel 7* in the spectrum. On channel 6, for example, 2x the 83.25 MHz visual carrier frequency is 168.50 MHz, while channel 7 (the next channel in line) has a visual carrier frequency of 175.25 MHz.

As long as CATV system operators were satisfied with 12 standard assignment VHF channels, the CATV industry had few real problems with *second order distortion* products. But, as soon as we began to think about our "empty spectrum" on our cable plants,

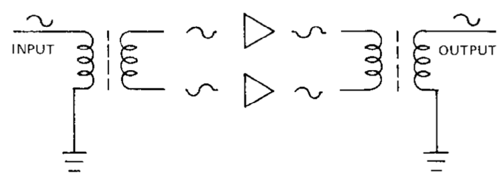

DIAGRAM 1

and wondering aloud how we might be able to force-feed additional TV channels through the cable and amplifiers, the *second order distortion* bird came home to roost!

For example, 2x channel 3 visual carrier frequency falls in mid-band channel "A". If it shows up at a high enough level on the cable plant, it will definitely show a herring-bone type of beat with any signal we happened to be cable-carrying on Channel "A" on our CATV plant.

To enable our industry to utilize the so-called mid-band channels between 6 and 7 (we generally speak of mid-band as starting around 120 MHz and running up to 174 MHz, although most users of cable do not use the full range [1]), the push-pull amplifier was developed.

WHAT IS PUSH-PULL?

Basically, a push-pull amplifier stage consists of two transistors (chips, etc.) operating electrically *180° out of phase* with each other, with the outputs combined through a transformer as illustrated in Diagram 1. Very cleverly the second order distortion products generated in the amplifier stage(s) are cancelled in the transformer (180° out of phase cancels), and this makes possible amplification over a frequency range that spans more than a single octave (2).

The typical amplifier stage operating on each side of a push-pull amplifier is a standard amplifier circuit with both current and voltage feedback (see CATJ, May 1974, Pages 40-46). The individual stage is designed flat or with 2-3 db maximum tilt by changing the feedback ratios. Input and output impedances are matched to 75 ohms. See Diagram 2 for a typical single stage. This type of circuit is exactly the same as a single ended amplifier, which was discussed in some detail in the May issue of CATJ.

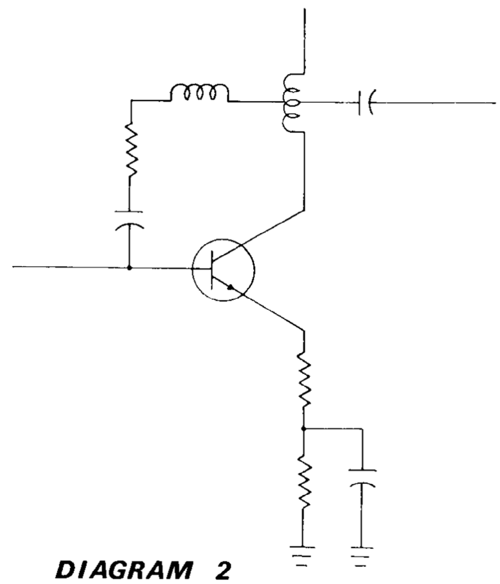

DIAGRAM 2

There have been two major designs for the development of a push-pull amplifier. The first we shall discuss utilizes a two-way splitter as its basic element. We are all aware that a two-way splitter divides the signal fed to it into a pair of separate but equal outputs. A 75 ohm splitter has a 75 ohm input and two 75 ohm outputs, and in a standard splitter the two (split) outputs are in phase (each with the other). Another way of describing a splitter is to call it a "balanced divider". See Diagram 3.

However, a push-pull amplifier circuit requires that the inputs to the opposing amplifier stages be *180° out of phase.* So, to the

(1) There is a tacit understanding between CATV system designers and the FAA that we will avoid the cable use of the 108-120 MHz spectrum for fear that cable radiation in that spectrum might be mistaken for an aircraft omni-beacon station and airplanes overhead might lock onto our cable plant radiation believing it to be an airport omni station.

(2) In CATV and other RF work, a frequency-octave is any doubling of the width of a given frequency span. For example, 50 (x2) = 100 MHz is one octave. Once at 100, 100 (x2) = 200 MHz is the next octave. Once at 200 MHz, 200 (x2) = 400 MHz is the next octave.

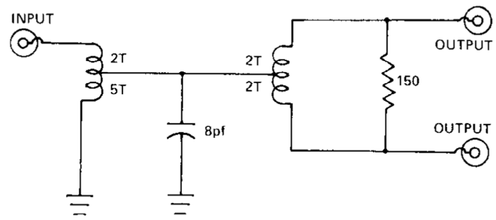

DIAGRAM 3

standard two-way. splitter (Diagram 3), we modify one of its output legs, or ports, by adding in a 1:1 transformer. This transformer does nothing to the impedance of that leg, but it does create a 180° phase reversal, or lag, in that leg. See Diagram 4.

With two signals of opposite phase, but equal level, we are now ready to drive the twin amplifier sections as shown in Diagram 5. Notice in Diagram 5, that the input signal is fed through the standard two-way splitter, into a phase shifting (1:1) network on one leg and into an amplifier stage on both legs. Stage A (amplifier 1) feeds directly into stage B (amplifier 2) on both legs.

After stage B on both legs, the side which was fed directly by the input two-way splitter now goes through a phase shifting network (1:1) and then both legs are recombined in a second two-way splitter, utilized now as a two-signal-combiner.

While in the push-pull portion of the amplifier as a whole, there is never any type

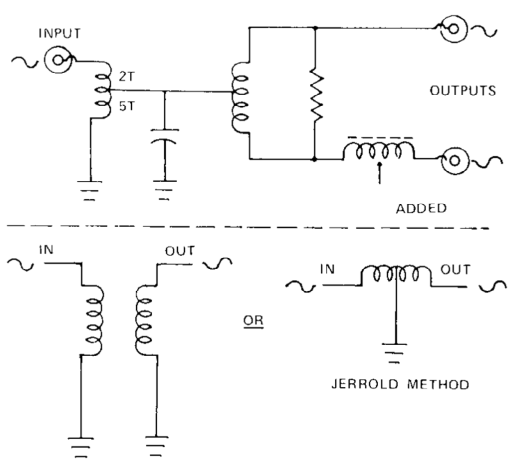

DIAGRAM 4

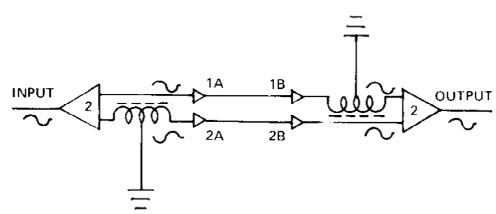

DIAGRAM 5

of gain control or tilt control employed. To do so while in the delicate phase-state in the two parallel legs of the push-pull amplifier would introduce a variable (or two) which would change the relative phases of the two legs beyond the point where they could be controlled. Gain and tilt are always employed in the amplifier stage(s) when the the signal is in an unbalanced mode.

In trouble shooting this type of push-pull circuitry (and it is the most popular approach to push-pull around), there are a number of areas which may be helpful to you:

(1) Because of the way that two-stages of push-pull are designed, *one or both* of the amplifiers on *one side* (i.e. 1A and 1B in Diagram 5) could fail and the total gain of the amplifier as a whole would *drop by only 6 db.*

(2) Each individual amplifier stage is a complete single ended amplifier and it should be viewed and trouble shot as outlined in the May issue of *CATJ,* Page 40.

(3) You should use a signal probe and follow the signal (RF) continuity through the amplifier on *one side,* and then on the other side (*CATJ* for May, Page 46). Keep in mind that relative to the input *to* the two-way splitter (on the input to the push-pull stage[s]) you will see a 3 db *loss* down any one leg, but that after the two-way splitter in the output of the two legs (i.e. re-combiner) you will see a 3 db *gain* relative to either leg alone.

(4) *NOTE:* The opposing transistor pairs in any push-pull amplifier (i.e. 1A and 2A) are carefully matched (one to the other) by the original

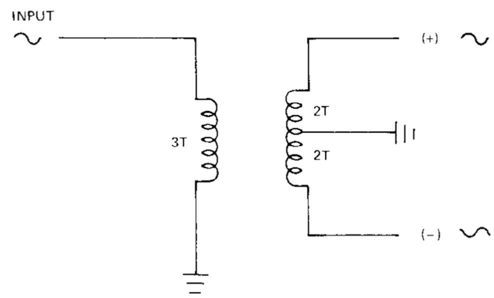

DIAGRAM 6

transistor manufacturer. It is very important to understand that if you are going to maintain phase parity between opposing stages, that *matched pairs, and only matched pairs, should be used.* Therefore, if you pop one transistor (i.e. 1A), you must replace that transistor, *plus* its opposing member (2A) *with a matched pair* provided by the transistor manufacturer or amplifier manufacturer. However, you can still use the *good member* of the pair later on, in a *single ended* amplifier stage. So discard only the bad one of the pair.

OTHER PUSH-PULL CIRCUITS

Other approaches to push-pull amplifier design follow the same basic pattern, but there are some innovations which you should understand in case your equipment utilizes one or more.

One major difference is the manner in which the out-of-phase signals are developed by the circuit designer. Diagram 6 illustrates a method by which a single transformer (rather than a two-way splitter plus 1:1 transformer on one leg) can create the phase reversal or imbalance required for a push-pull amplifier.

With a turns ratio of 3 turns on the input and a turns ratio of 4 turns on the output side of the transformer, we will end up with 180° phase reversal on the two legs. This deletes both the two-way splitter and the 1:1 transformer.

FULL PUSH-PULL AMPLIFIER

A typical push-pull line extender will have four stages of amplification. The first two will be *single ended* and it will be in these stages where the gain and tilt controls are located. Following the two single ended stages will be the two (pairs of) push-pull stages. See Diagram 7.

Normally a plug-in type of cable equalizer is also employed in these amplifiers. It is placed at the input to the amplifier (see Figure 17, Page 45, May *CATJ*).

Push-pull amplifier stages are normally biased like single ended amplifier stages. There is one exception, as shown in Diagram 8.

Notice in Diagram 8 that the base bias voltage developed by R1 and R2 is fed to the center tap of transformer T1 and is then fed to the base of both transistors. This is done for two reasons:

(1) It removes three component parts from the circuit.

(2) It *forces* both transistors to accept the same identical base bias condition.

Also, notice that resistor R5 is common to both circuits. This again removes a component part from the circuit, and it maintains both transistors at exactly the same collector current levels.

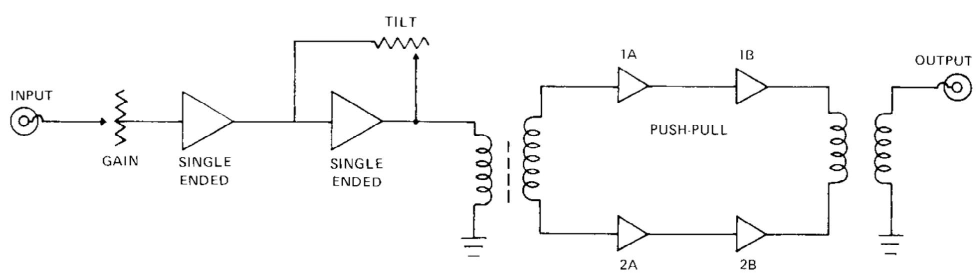

DIAGRAM 7

In a push-pull amplifier, it is not enough that only the transistors are matched. So too must every ingredient in each opposing stage of the amplifier be matched. With the advance of technology, the industry is finding ways to make more and more certain that the equal but opposite in phase integrity of the opposing amplifiers is maintained.

It is possible to make push-pull circuits compensate for cable losses (i.e. tilt or slope), but in doing so, certain elements are added to the circuit which are unique to only wide band RF push-pull amplifiers.

Diagram 9 shows a technique developed to control the very low end of the RF bandpass response range. The two collectors of the two transistors in opposition are tied together through a low pass filter and a potentiometer. The *collectors are 180° out of phase* with one another and any signal (coupled through the low pass filter) transmitted between the two is cancelled (adjustment of the pot), which is a very effective low-end control scheme.

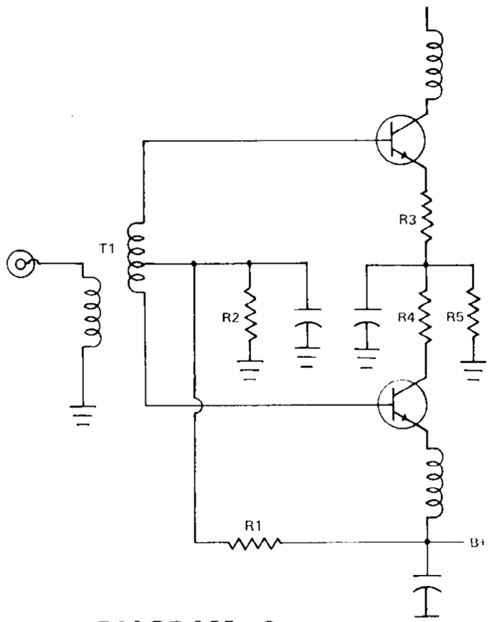

DIAGRAM 8

At times, it becomes necessary to peak the very high end of a push-pull bandpass response amplifier. This can be done, as shown in Diagram 10, by connecting an R-C network between the emitters of the two opposing stages. As the two emitters are 180° out of phase with one another, this form of *emitter degeneration* (May *CATJ*, Page 44) allows the adjustment of peaking of the high end.

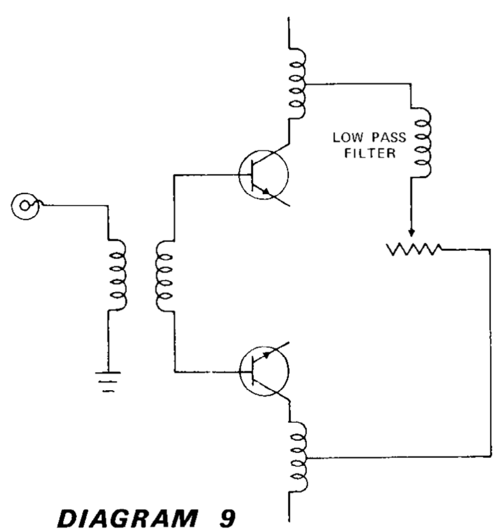

DIAGRAM 9

CATJ SUBSCRIPTION - WALL CHART ORDER CARD

YES–

. . . .**I wish to subscribe to CATJ** for my system/business. I enclose payment in full of **$10.00** for 12 issues.

. . . .**I am a technician** employed by a CATV system/business and I wish to subscribe to CATJ at my home. My payment of **$7.00** for the special technician annual subscription is enclosed.

. . . .**I wish to order CATJ Head End Wall Charts** as follows:
. . . . 1 for **$5.00** . . . . 2 for **$9.00** . . . . 3 for **$12.00,** payment is enclosed.

Name ______________________________

Company (if applicable) ______________________________

Address ______________________________

Town/City ____________________ State __________ Zip __________

Place in Envelope with Payment and mail to:
CATJ - Community Antenna Television Journal
4209 N.W. 23rd. St., Suite 106
Oklahoma City, Oklahoma 73107

YES–

. . . .**I wish to subscribe to CATJ** for my system/business. I enclose payment in full of **$10.00** for 12 issues.

. . . .**I am a technician** employed by a CATV system/business and I wish to subscribe to CATJ at my home. My payment of **$7.00** for the special technician annual subscription is enclosed.

. . . .**I wish to order CATJ Head End Wall Charts** as follows:
. . . . 1 for **$5.00** . . . . 2 for **$9.00** . . . . 3 for **$12.00,** payment is enclosed.

Name ______________________________

Company (if applicable) ______________________________

Address ______________________________

Town/City ____________________ State __________ Zip __________

Place in Envelope with Payment and mail to:
CATJ - Community Antenna Television Journal
4209 N.W. 23rd. St., Suite 106
Oklahoma City, Oklahoma 73107

YES–

. . . .**I wish to subscribe to CATJ** for my system/business. I enclose payment in full of **$10.00** for 12 issues.

. . . .**I am a technician** employed by a CATV system/business and I wish to subscribe to CATJ at my home. My payment of **$7.00** for the special technician annual subscription is enclosed.

. . . .**I wish to order CATJ Head End Wall Charts** as follows:
. . . . 1 for **$5.00** . . . . 2 for **$9.00** . . . . 3 for **$12.00,** payment is enclosed.

Name ______________________________

Company (if applicable) ______________________________

Address ______________________________

Town/City ____________________ State __________ Zip __________

Place in Envelope with Payment and mail to:
CATJ - Community Antenna Television Journal
4209 N.W. 23rd. St., Suite 106
Oklahoma City, Oklahoma 73107

CATJ SUBSCRIPTION - WALL CHART ORDER CARD

AUGUST 1974
SUBSCRIPTION ORDER
CARD NUMBER ONE

AUGUST 1974
SUBSCRIPTION ORDER
CARD NUMBER TWO

AUGUST 1974
SUBSCRIPTION ORDER
CARD NUMBER THREE

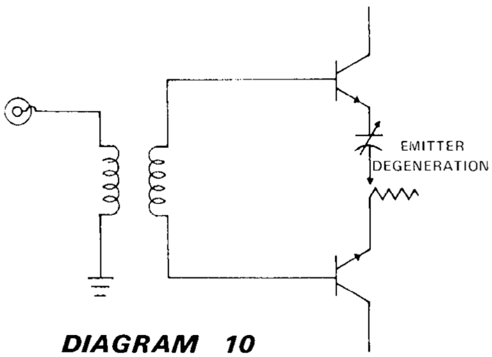

DIAGRAM 10

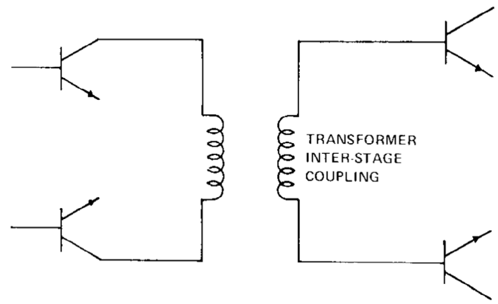

DIAGRAM 11

Normally, in push-pull blocks, the upper and lower halves are directly coupled to each other. However, it is possible to transformer couple the stages together as illustrated in Diagram 11.

SYSNOPSIS

Understanding *how a push-pull amplifier works*, what you can do to repair it, and what you *cannot* do in an emergency should make you a better system operator.

Furthermore, knowing when you need push-pull circuitry and when you do not will perhaps save you valuable plant investment or expansion dollars. If your plant is now, and always will be, a 12 channel standard frequency assignment system (i.e. no use of mid-band channels), your single ended amplifiers are going to work just fine. On the other hand, if you now plan, or someday intend, to make utility use of the mid-band region, push-pull is one of the design criteria which you must accept and plan for now.