# DESIGN CONSIDERATIONS FOR A BANDWIDTH EFFICIENT SPLIT-BAND TRUNK STATION

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## Abstract

Technical considerations for the design of a bandwidth efficient split-band trunk amplifier are discussed with some highlights on the choice of diplex filters and their effect on the performance of the amplifier. A comparison is given between guardband requirements for a standard 30/50 MHz sub-split amplifier and those for a 186/222 MHz split-band amplifier. Some practical considerations are outlined concerning the structure of the reverse amplifier module, and how the closed loop pilot controlled PIN Diode attenuator plays a major role in maintaining reverse system flatness. System performance specifications and test data are presented for a split-band gear with a reverse bandwidth of 5-186 MHz and forward bandwidth of 222-450 MHz.

## 1. Introduction

Mid-split systems of the mid-70's were straight-forward extensions of sub-split technologies that wasted and inefficiently used available bandwidth. Even so, interest in them remained. Today, a split-band amplifier with an upper frequency of 450 MHz and a spectrum allocated equally to forward and reverse systems is in demand. Design techniques for such a system are discussed in this paper. We will consider guardband characteristics, filter requirements, reverse level control, and reverse amplifier topology, and will describe a system with a 5-186 MHz/222-450 MHz spectrum and a guardband loss of only 6 channels.

## 2. Guardband Characteristics

When system designers plan broadband communications with equal bandwidth in both directions on a single cable, they must sacrifice a portion of the spectrum to stabilize amplifier operation.

The allowable spectrum consists of: the reverse passband, the guardband, and the forward passband. Any guardband is a loss of bandwidth, is useless for information transfer, and should be kept to a minimum.

Designers have recently increased the channel-carrying capabilities of broadband systems from 300 MHz to 330, 360, 400, and 450 MHz. This rise in frequency has been built on transistors with higher output power, more channel-carrying capability, and better performance. Generally, equipment designers have found sufficient challenge in modifying the supplemental circuits to guarantee operation at higher frequencies. In particular, gain adjust, slope adjust, level control circuitry, and RF chokes had to be re-worked. This design was difficult; considerable developmental time had to be allotted. Nevertheless, the theory was an extension of existing basic philosophies. We could not satisfactorily produce split-band amplifiers with 400 or 450 MHz upper frequencies by simple extensions of technology.

We began by comparing existing standard splits of the broadband spectrum (Figure 1). Of the four systems, the first is a standard sub-split system of the late 1960's and early 1970's. The reverse portion of the spectrum was 5-30 MHz while the forward was 50-300 MHz. A 20 MHz guardband centered at 40 MHz was standard.

The second bar illustrates a standard mid-split system in use around 1972; this one provided a more equal spectrum distribution with a larger reverse passband. These systems had a 5-108 MHz reverse passband with a 66 MHz guardband centered on 141 MHz and were designed to meet franchising requirments of the early 1970's. Since the recession of the mid 1970's, cable system operators had little use for split-band communication equipment until recently when

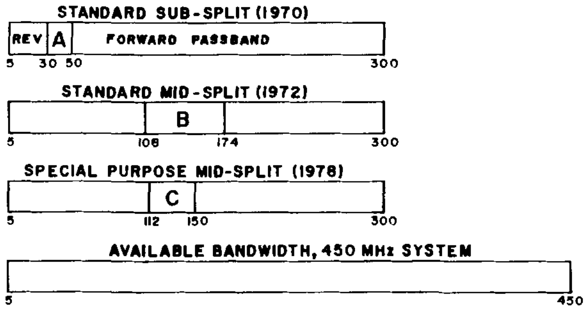

FIGURE 1
A COMPARISON OF EXISTING "STANDARD" SPLITS
OF BROADBAND SPECTRUM

franchising activities grew and broadband local area networks emerged. The only exception was a broadband telephone/cable television system attempted by a non-CATV company (see third bar of Figure 1) as a special-purpose mid-split and put into operation in 1978. Shown are reverse passband frequencies of 5-112 MHz, forward passband frequencies of 150-300 MHz, and a guardband of 112-150 MHz centered on 131 MHz. The technology was upgraded and the spectrum better utilized, but the system remained an exception.

The fourth bar of Figure 1 illustrates the available bandwidth in a 450 MHz system.

Filter quality is the key to successful split-band amplifiers. For this discussion, the filter types used in the three systems shown will be labeled as types A, B, and C. We will define filter quality in two terms: (1) the ratio of guardband width to the guardband center frequency, and (2) the ratio of the assigned guardband width to the total available bandwidth (see Table 1). Actually, the poorest filtering is in the sub-split systems where the guardband is a full 50 percent of the center frequency. However, this guardband width is only 7 percent of the available bandwidth and only 3.3 channels are lost. The mid-split 108/174 systems contained filters of similar quality, but merely shifted up in frequency to operate with a center frequency of 141 MHz. Here, we see considerable waste; the guardband occupied 22 percent of the available bandwidth; and a full 11 channels were lost. Type C filters designed around special-purpose amplifiers improved performance: 13 percent of the available bandwidth was used; 6.3 channels were lost; and the guardband occupied 29 percent of the center frequency. If we use these filters in an equal-split 450 MHz system, the results would be undesirable. Table 2 lists calculated performances for 450 MHz systems with guardband characteristics of the three previous 300 MHz split-band systems. From 9 to 16 channels are lost and from 13 to 25 percent of the available bandwidth is wasted for guardband use.

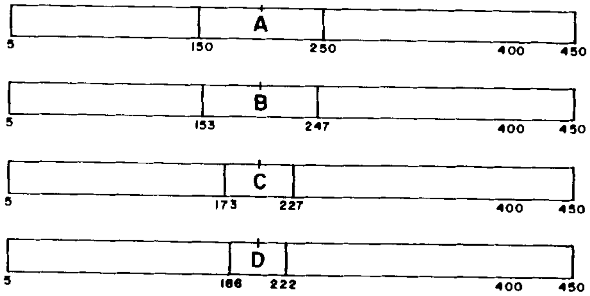

**FIGURE 2**
**COMPARISON OF EXISTING TECHNOLOGIES WITH A MORE EFFICIENT SCHEME FOR 400/450 MHz"EQUAL SPLIT"SYSTEMS**

Figure 2 illustrates 400 and 450 MHz systems using Type A, B, and C filters as well as the more efficient Type D, which only loses 6 channels. Naturally, Type D filters more efficiently use available bandwidth.

| | | Guardband Efficiency % | | |
|---|---|---|---|---|
| Filter Type | Bandpass, MHz | of Center Frequency | of Total Bandwidth | Lost Channels |
| A | 5-30,<br>50-300 | 50 | 7 | 3.3 |
| B | 5-108,<br>174-300 | 47 | 22 | 11.0 |
| C | 5-112,<br>150-300 | 29 | 13 | 6.3 |

TABLE 1
Relative Performance of Existing Systems

## 3. Filter Characteristics

Crossover filter design is crucial to split-band equipment performance. Desirable characteristics include a flat passband, constant passband time delay, a sharp cutoff at transition, and a specific minimum attenuation of the stop-band. Two design factors are particularly important. The first is that sharp attenuation cutoffs and constant time delays are incompatible.[1] The second is that attenuation characteristics are the dominant requirement for stable trunk station operation.[2] Chebyshev filters offer minimum

| | | Guardband Efficiency % | | |
|---|---|---|---|---|
| Filter Type | Bandpass, MHz | of Center Frequency | of Total Bandwidth | Lost Channels |
| A | 5-150,<br>250-450 | 50 | 23 | 17 |
| B | 5-153,<br>247-450 | 47 | 21 | 16 |
| C | 5-173,<br>227-450 | 29 | 12 | 9 |
| D | 5-186,<br>222-450 | 18 | 8 | 6 |

TABLE 2
450 MHz Split-Band Peformance
Using Several Filter Types

transition range for reaching a prescribed attenuation, and never provide a stopband attenuation less than the prescribed attenuation. We, therefore, chose Chebyshev filters. In the following sections, we discuss group delay characteristics and passband flatness.

### 3.1 Group Delay Characteristics

Chebyshev filter group delay depends on two variables. The first is filter complexity or number of filter branches. The second is cutoff frequency. Group delay will rise as filter complexity increases and will decrease as cutoff frequency rises. Group delay is more strongly dependent on cutoff frequency than it is on filter complexity, thus, Chebyshev filters for a split-band amplifier have less group delay than their sub-split counterparts. Figures 3 and 4 compare group delay of split-band filters with sub-band filters. (30 MHz sub-split, 112 MHz and 186 MHz split-band, low pass filters).

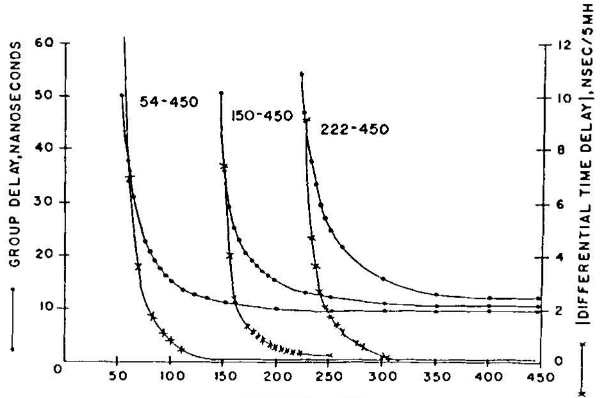

FIGURE 3

FORWARD BANDPASS GROUP DELAY AND DIFFERENTIAL GROUP DELAY FOR SEVERAL TRUNK STATIONS

### 3.2 Differential Group Delay

Although absolute group delay of higher frequency split-band filters is less than that of sub-split filters, the same is not necessarily true of the differential group delay (the change in group delay with the frequency change). Figures 3 and 4 plot change in group delay versus frequency change for 5 MHz increments throughout the reverse and forward passbands of the individual filter and also the trunk station. These numbers are compared to those for a typical sub-split trunk station.

### 3.3 Passband Flatness

Filter complexity and passband ripple define the sharpness of attenuation cutoffs in a Chebyshev filter. Attenuation transition regions can be sharpened by accepting a higher passband ripple with attendant higher band-edge roll off and then balancing this specification against lower filter complexity.

Naturally, we must add appropriate amplitude distortion equalizers on the reverse amplifier interstage if we want higher passband ripple. Figure 5 shows the response of an eight-branch Chebyshev diplexing filter with a 186/222 transition range.

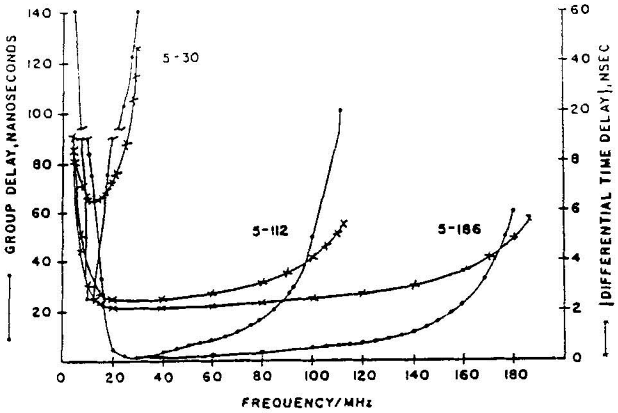

FIGURE 4

REVERSE BANDPASS GROUP DELAY AND DIFFERENTIAL GROUP DELAY FOR SEVERAL TRUNKS

### 3.4 Filter Alignment

Increased filter complexity imposes a price: More time will be required for alignment. It is also necessary to pay strict attention to filter stop-band attenuation, pole location, and crossover isolation, if we wish to provide adequate amplifier flatness and unconditional stability. Cross-over isolation of diplex filters

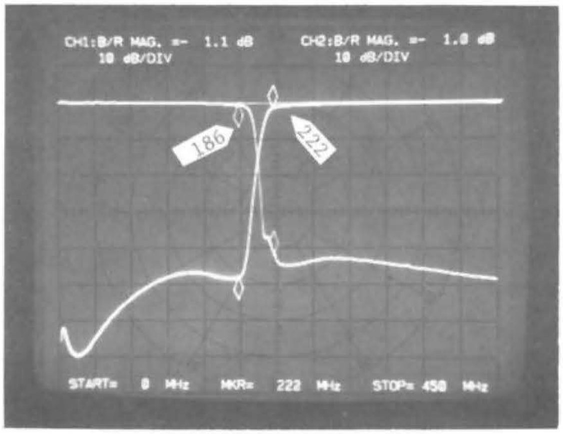

FIGURE 5

SWEPT RESPONSE OF 186/222 DIPLEX FILTER

in this application will degrade significantly when the combined port is unterminated, therefore, filters must be tested at a minimum crossover isolation specification under both terminated and unterminated conditions. Plug-in filters make this test easier; filter specialists can then align them in production tests, instead of trunk station alignment technicians.

## 4. Level Control

Open loop methods of reverse level control had proven practical in sub-split and split-band systems with reverse passband upper frequencies of 108 MHz and below. These circuits used a negative temperature coefficient thermistor as a series element in a bridged-T structure or as a series component in the RF signal path. But increased gain necessary in higher frequency split-band units and use of more channels significantly reduces dynamic range and mandates tight level control. We turned to PIN Diodes, which provide positive as well as negative resistance changes and are controllable by either closed or open loop methods. To control short systems with moderate temperature changes, we would choose a thermally driven PIN Diode circuit. In longer systems with wide temperature excursions, open loop is no longer satisfactory, and closed loop level control is the choice.

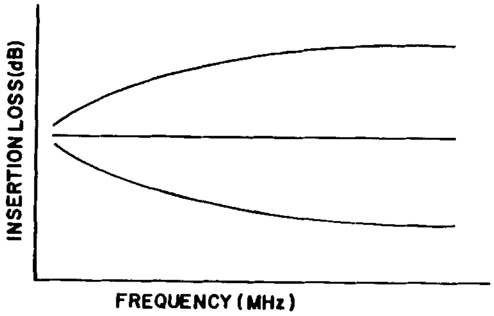

FIGURE 6
SLOPE COMPENSATED ATTENUATOR RESPONSE

Control of reverse system gain with closed loop method is not problem-free. If closed loop control is installed at every return trunk station, each extremity of a standard cable system would require a pilot signal generator. Then, the pilot on spur trunks would have to be trapped out so that combining pilots do not interfere or overload the system. Pilot signals must be kept to a minimum.

For this reason, a slope-compensated Automatic Level Control (ALC) using a single pilot is better than the dual-pilot approach of separate Automatic Gain Control (AGC) with separate Automatic Slope Control (ASC). Slope-compensated level control circuitry has characteristics similar to those in Figure 6. In this system, a single pilot operates at the high frequency, and the RF attenuator precisely and accurately compensates for cable loss changes. In this way, each trunk station requires only a single closed loop. Since system stability and transient response is a function of the number of control loops,[3] a slope-compensated approach to level control is strongly desirable. This design cuts in half the number of control loops.

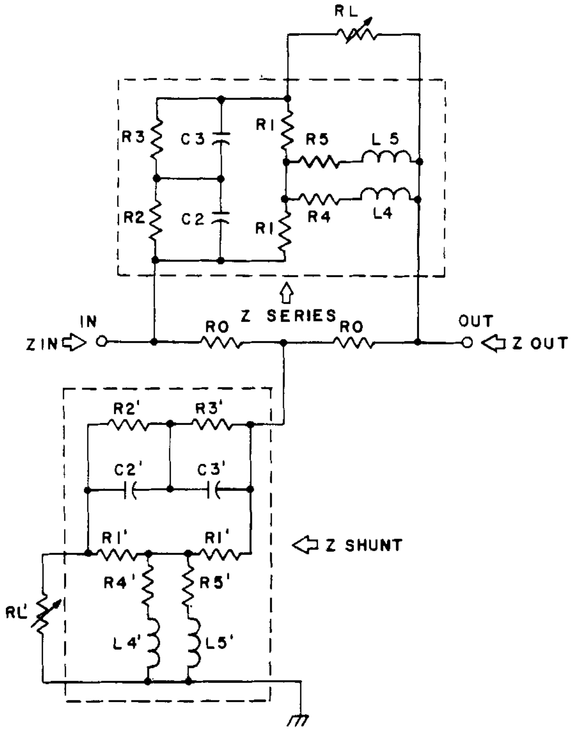

FIGURE 7
SCHEMATIC DIAGRAM OF A MULTIPLE OCTAVE GAIN CONTROL CIRCUIT.

The circuit (Figure 7) controls the RF attenuator with sufficient precision to produce slope-compensated ALC. Provided is a 5 1/2-octave response to cable attenuation changes.[4]

### 4.1 ALC System Summary

We built our level control system on thermally controlled PIN Diode RF attenuators added to all short spur trunks. For long cascades, thermally driven circuits predominate, but closed loop ALC reverse amplifiers are installed at every third amplifier (two out of three RA's are controlled thermally). We also specify pilot generators on main trunk lines; and call for pilot traps at intersections of pilot-controlled trunklines. (See Figure 8).

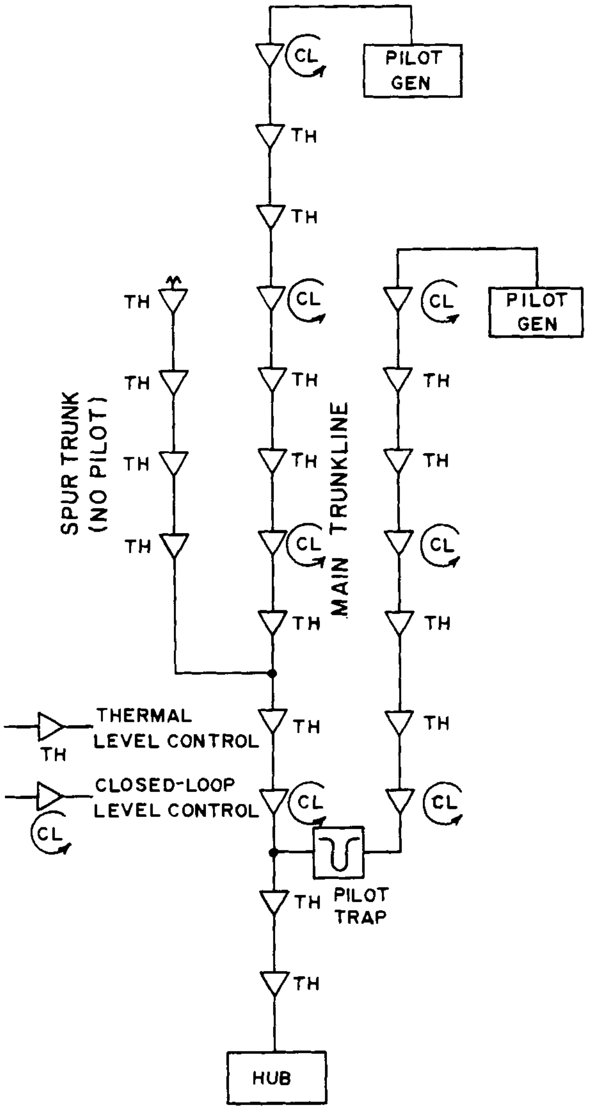

FIGURE 8

REVERSE SYSTEM LEVEL CONTROL

These figures assume 21 dB forward spacing at the highest frequency. Allowance for 8.5 dB flat loss between stations requires 16.4 dB reverse spacing. A rise in upper frequency of the forward section decreases reverse spacing; a rise in upper frequency of the return system increases return spacing.

## 5. The Reverse Amplifier

Reverse amplification in equal split-band 400 or 450 MHz systems is based on level control, loop gain requirements, trunk station reverse spacing, plus allowance for several controls, test points, and connectors normally associated with trunk amplifiers. We will discuss each and then combine all requirements into a logically optimized amplifier configuration.

| BANDWIDTH, MHz | | REVERSE SPACING, dB | |
|---|---|---|---|
| Reverse | Forward | Full Cable | With 8.5 dB Flat loss |
| 5-30 | 50-300 | 6.0 | 12.1 |
| 5-30 | 50-450 | 4.9 | 11.4 |
| 5-108 | 150-300 | 12.1 | 15.7 |
| 5-108 | 150-450 | 10.4 | 14.3 |
| 5- 186 | 222-450 | 13.3 | 16.4 |

TABLE 3
Reverse Spacing For Various Systems

### 5.1 Loop Gain

The topology of a two-way broadband amplifier provides a feedback path that impresses an undesired signal on forward and return paths. Filtering must prevent passband gain perturbations and guardband oscillations through adequate loop gain (or loss). Adding all the available loop gains and losses determines amplifier loop gain. In the passband, a 40 dB loop loss is required to guarantee amplitude perturbations lower than 0.1 dB. In the guardband, at least 10 dB loop loss is necessary to prevent oscillations.

Two loops were considered in our trunk station design. Figure 9 illustrates trunk station topology used to calculate loop gains. Loop 1 includes the trunk forward amplifier and Reverse Amplifier (RA), plus trunk input and output filters. Loop 2 includes the trunk, bridger, reverse amplifier, trunk input filter, and bridger output filter. Assuming that trunk forward gains are 21, 16, and 36 dB respectively, trunk input and output filter stopband rejections of 40 dB each would provide adequate trunk

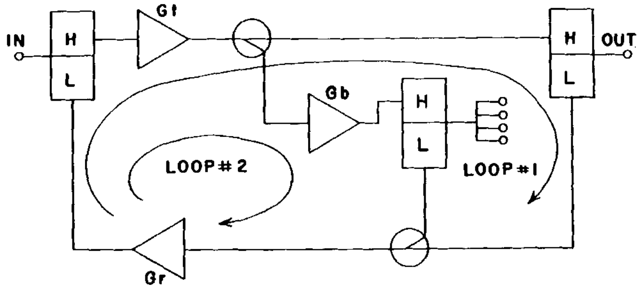

FIGURE 9

TRUNK TOPOLOGY
FOR LOOP GAIN CALCULATIONS

flatness. Consequently, the Bridger Amplifier (BA) output filter would need about 50 dB stopband rejection to guarantee adequate trunkline passband flatness. This much rejection is difficult to achieve. Instead, we inserted another filter in the RA loop, and furnished 30 dB stopband rejection in both the RA and BA output filter.

## 5.2 Reverse Spacing

Several two-way system reverse spacings are shown in Table 3. Sub-split and split-band systems for both 300 and 450 MHz operation appear. The split-band systems show a 108/150 split, plus a 186/222 split for the 450 MHz system.

| | |
|---|---|
| Trunk Input Filter | 0.9 |
| Trunk Output Filter | 0.9 |
| External Test Points (2) | 0.7 |
| Return Combiner | 1.5 |
| Slope Adjust Pot | 2.0 |
| Gain Adjust Pot | 0.5 |
| Lowpass Filter | 0.5 |
| Flatness Circuit | 1.0 |
| ALC with 2.5 dB Reserve | 4.5 |
| ALC Pick-off DC | 0.5 |
| Plug-in Cable EQ | 1.0 |
| Total Losses | 14.0 dB |

TABLE 4
Loss Budget for Trunk RA

These figures assume 21 dB forward spacing at the highest frequency. Allowance for 8.5 dB flat loss between stations requires 16.4 dB reverse spacing. A rise in upper frequency of the forward section decreases reverse spacing; a rise in upper frequency of the return system increases return spacing.

## 5.3 Reverse Amplifier Design

As noted previously, our reverse amplifier design includes a PIN Diode ALC circuit, a low-pass filter, and 16.7 dB spacing. The closed loop ALC uses a directional coupler on the RA output. Additionally, losses in trunk I/O filters, external test points, and controls for slope, reverse gain, etc. must be included. Table 4 lists them; they amount to 14 dB. Therefore, the total active gain block requirement of the RA is equal to 14 + 16.7 or 30.7 dB minimum.

This total gain is only slightly less than forward amplifier gain requirements and is best attained with two gain blocks (Figure 10). The flatness equalizer, slope, ALC, and filter are interstage; the plug-in cable equalizer and gain adjust are placed on the reverse amplifier output. The unit operates in a "constant input" mode and minimizes amplifier noise, while allowing the system designer to place splits in the trunkline without degrading reverse system performance.

## 6. Conclusion

Our design achieves efficient use of the available spectrum. Rather than degrade performance, the resultant increase in filter circuit complexity improves the system, since the guard-band center frequency moves upward. Through use of plug-in filters alignment becomes easier, amplifier stability remains high under mismatched termination conditions, and final trunk assemblies undergo easier production tests. Reverse amplifier complexity is increased to the point where reverse and forward amplifiers have nearly the same functional performance requirements.

## References

[1] Zverev, A., Handbook for Filter Synthesis, John Wiley and Sons, Inc., 1967.

[2] Marron, H. B., Barnhart, A. W., "System Considerations in the Design of a Two-Way Transmissions System," NCTA Convention Transcripts, 1970.

[3] Chisolm, Eric, "Considerations on the Application of AGC/ASC Amplifiers in CATV Systems," IEEE Transactions on Cable Television, Volume CATV-1, No. 1, October 1976.

[4] Preschutti, J. P., Kyle, C. A., "A Five-Octave Level Control Circuit for Broadband Coaxial Cable Distribution Systems," IEEE Transactions on Broad casting, March 1983.

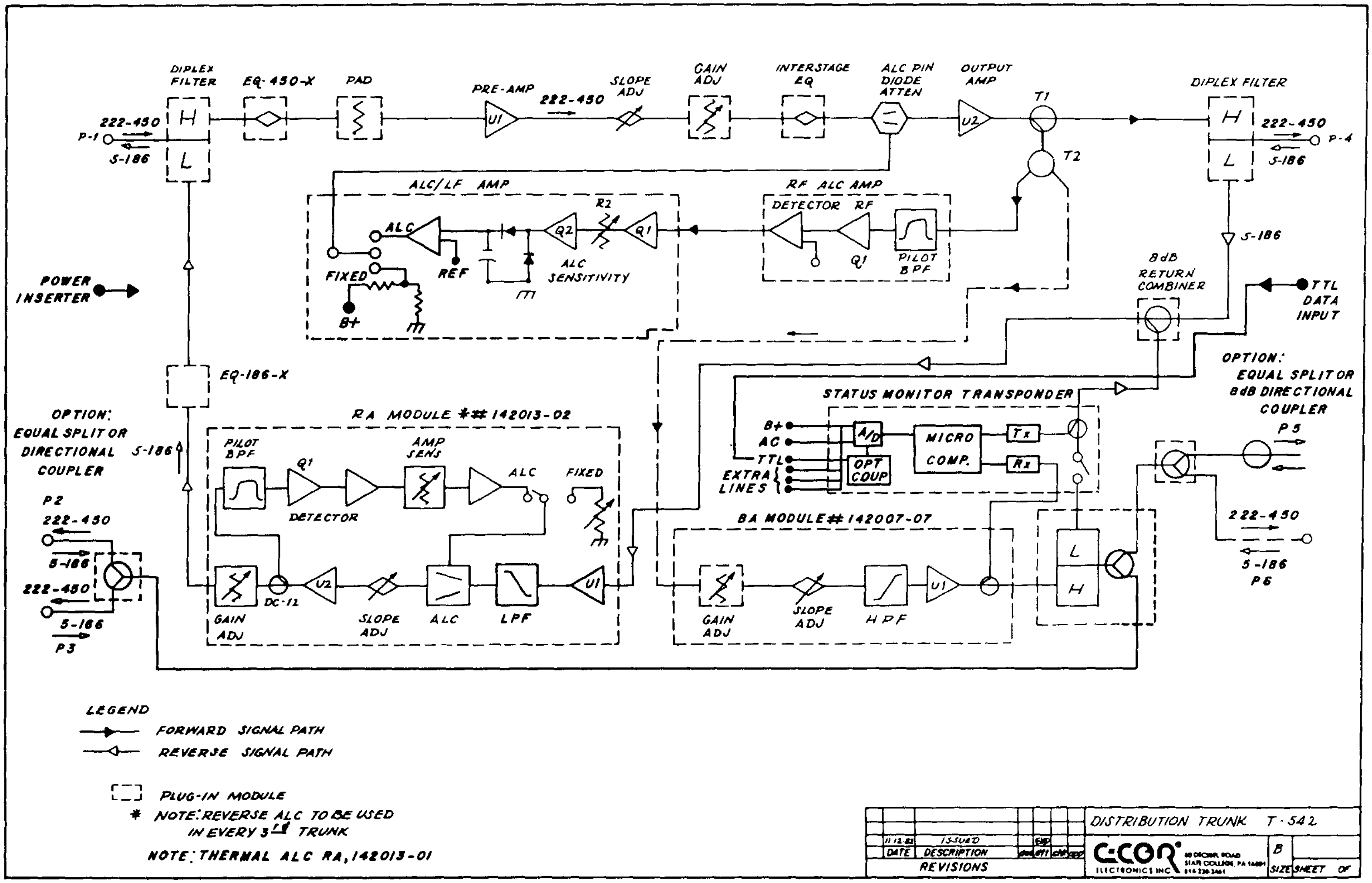
DIPLEX FILTER
H
L
EQ-450-X
PAD
PRE-AMP
U1
222-450
SLOPE ADJ
GAIN ADJ
INTERSTAGE EQ
ALC PIN DIODE ATTEN
OUTPUT AMP
U2
T1
T2
DIPLEX FILTER
222-450
P-1
5-186
222-450
P-4
5-186
ALC/LF AMP
ALC
REF
FIXED
B+
R2
Q2
Q1
ALC SENSITIVITY
RF ALC AMP
DETECTOR
RF
Q1
PILOT BPF
5-186
8dB RETURN COMBINER
TTL DATA INPUT
POWER INSERTER
EQ-186-X
OPTION: EQUAL SPLIT OR DIRECTIONAL COUPLER
5-186
P2
222-450
5-186
222-450
5-186
P3
RA MODULE *# 142013-02
PILOT BPF
Q1
DETECTOR
AMP SENS
ALC
FIXED
GAIN ADJ
DC-12
U2
SLOPE ADJ
ALC
LPF
U1
STATUS MONITOR TRANSPONDER
B+
AC
TTL
EXTRA LINES
A/D
OPT COUP
MICRO COMP.
Tx
Rx
OPTION: EQUAL SPLITOR 8dB DIRECTIONAL COUPLER
P5
BA MODULE # 142007-07
GAIN ADJ
SLOPE ADJ
HPF
U1
L
H
222-450
5-186
P6
LEGEND
FORWARD SIGNAL PATH
REVERSE SIGNAL PATH
PLUG-IN MODULE
* NOTE: REVERSE ALC TO BE USED IN EVERY 3rd TRUNK
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FIGURE 10