CONSIDERATIONS FOR SIGNALS IN THE REVERSE FEEDER LINES

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Abstract - Emphasis is placed on system design criteria for subscriber originated signals. Methods for establishing proper system operating levels based on system size are considered and the performance trade-offs are analyzed. System levels are established on an exemplar profile and the resultant component requirements examined. An examination of potential subscriber interference through propagation is made with recommended techniques for correction offered.

Introduction

In CATV systems providing one-way signal transportation, the "quality control" emphasis has been on the trunk line with secondary attention being given to the feeder or distribution line. Such a philosophy is justified, of course, when one considers the relatively complex requirements of headend antenna arrays, signal processors, trunk amplifier distortion and response stability criteria, as compared to the job of the directional multitap and line extender, or even the distribution bridger. In much of the analysis work pertaining to two-way signal transportation again the primary emphasis has been placed on trunk or total system design, with the feeder system assigned to an ancillary position. There are, however, a number of design considerations relating particularly to the distribution or feeder legs of two-way systems which are worthy of special attention. It is the purpose of this paper to present the following points for consideration: 1) the operating levels and performance specifications of the feeder system should be established on the basis of actual trunk to feeder density as well as total system size; 2) the feeder system operating levels should not be higher than the minimum dictated by the desired system performance standards to avoid requiring excessively high outputs from the subscriber return terminals; 3) potential two-way interference paths exist, particularly in installations with high terminal density (i.e. schools, hospitals, etc.) which will require special attention; and 4) return feeder system operating level changes as a result of temperature variations, while less than in the forward direction, are still significant and should be controlled.

Elements of the Feeder System

Illustrated in Figure 1 is a segment of a typical two-way trunk and distribution layout. The hub concept is shown since this is perhaps the most viable scheme for new systems, but the same basic problems confront all types of systems and are simply easier to isolate with the hub concept.

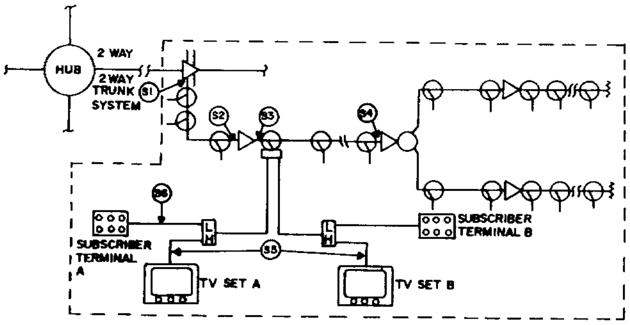

FIG. 1 FEEDER SYSTEM INDICATING SIGNIFICANT POINTS FOR ESTABLISHMENT OF RETURN SIGNAL PERFORMANCE

There are six significant locations (S1 - S6) where feeder levels must be controlled in order to realize an optimum system design. The first of these to be established is the level at S1 (bridger input) and S3 (feeder inputs), which are the system "minimum signal levels". In order to appreciate the level requirements at these points consider the effect which has been termed noise - "summing" or "gathering".

System Noise Level

The basic result of summing non-coherent signals with equal noise using splitters is shown in Figure 2, with the result being that the effective signal-to-noise ratio is decreased 3 dB each time the number of noise sources is doubled. If we carry the analysis one step further it can be shown that the total noise contribution of combining any number of these equal noise sources together is expressed by the relation:

$$\text{System noise} = NS = NT + 10\ \text{Log}_{10}\ N$$

Where NT = Thermal noise (4 MHz) = -59 dBmV

N = Total number of noise sources

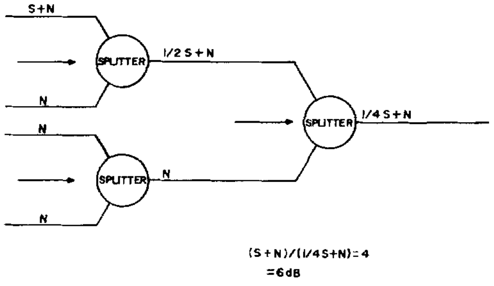

FIG. 2 BASIC NOISE SUMMING EFFECT OF SIGNAL COMBINING

This is really no different than calculating cascade noise build up except that we are now concerned with system density rather than length. For example, in a cascade of 40 amplifiers with equal noise figures, the noise level at the end of the cascade with an 8 dB amplifier noise figure is given by the expression:

System noise = NS = NT + 10 Log_{10} N + NF
= -59 + 10(1.6) + 8 = -35 dBmV

Where NF = Amplifier noise figure
NT = Thermal noise (4 MHz) = -59 dBmV
N = Total number of amplifiers

and the signal-to-noise ratio would therefore be:

S - N = S - (-35 dBmV) = S + 35 dBmV

In a similar manner the noise level produced at the summation point due to two (2) cascades of 20 amplifiers feeding into each port of an ideal (-3 dB) line divider with amplifier noise figures of 8 dB is found by the expression:

System noise = $NS_1 \oplus^* NS_2$ = -38 dBmV

Where $NS_1 = NS_2$ = (-59 + 10 Log_{10} 20 + 8) -3
= -41 dBmV

and the signal-to-noise ratio would be:

S - N = (S - 3 dB) - (-38 dBmV) = S + 35 dBmV

*denotes logarithmic addition

Since we are interested in the signal or carrier to noise ratio in a CATV system we will need to consider not only the noise build up of the feeder lines, but the required minimum signal levels as well. The accumulation of noise per se would not be a problem if it were possible to subsequently increase the desired signal as needed, thus maintaining a constant noise margin. Such is not the case, however, and promiscuously increasing the minimum operating level beyond that which is needed may place an unnecessary burden on other areas of the system (i.e. requiring excessive subscriber terminal levels or amplifier distortion characteristics).

Signal-to-Noise Ratio

The graph shown in Figure 3 depicts the minimum signal level required at a bridger summation point to maintain a selected signal-to-noise ratio from the feeder system. If we let, for example, the complete feeder system S/N = 49 dB then a total of 100 amplifiers in the feeder system would require a minimum summation signal of +18 dBmV and 1,000 amplifiers would require a minimum summation signal of +30 dBmV.

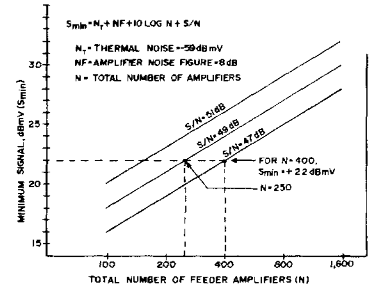

FIG. 3 RELATIONSHIP BETWEEN SYSTEM DENSITY AND MINIMUM SIGNAL LEVEL

If the S/N ratio of the complete return path, (trunk and feeder system) is set, for example, at 46 dB, a design trade-off may now be made.

TABLE I

TABULATION OF TRUNK / FEEDER S/N

TRUNK S/N (dB)	FEEDER S/N (dB)	COMBINED S/N (dB)
46.5	56.0	46
47.0	53.5	46
48.0	50.5	46
49.0	49.0	46
50.5	48.0	46
53.5	47.0	46
56.0	46.5	46

Table I tabulates a few of the many combinations of trunk and feeder S/N ratios which will yield an overall S/N of 46 dB. However, although many combinations of trunk/feeder ratios are possible, a condition of disproportionate loading is quickly encountered. Figure 4 graphically displays this condition, and the shaded area represents a boundary which is equal to ±2 dB from the equipollent position. While this may seem like a meager design trade-off, Figure 3 demonstrates that decreasing the feeder S/N from 49 dB to 47 dB increases the number of permissible feeder amplifiers from 250 to 400. This represents a potential increase of 4,200 subscribers (Appendix I) without sacrificing picture quality or raising the required signal level. Since the composite return system (trunk and feeder) S/N must be held at 46 dB, the trunk system must now yield a S/N of 53.5 dB (Table I). If the feeder to trunk ratio is high (i.e. greater than 4:1) this may be a very reasonable trade-off since S/N ratios of 53.5 dB may be realized for trunk systems of up to 90 amplifiers with equipment currently available (Appendix II). Having demonstrated

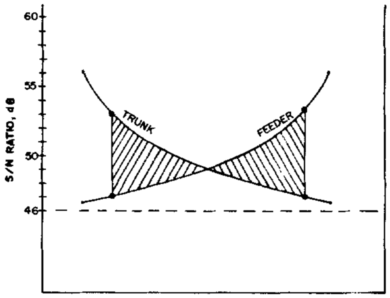

FIG. 4 COMBINATIONS OF TRUNK/FEEDER S/N RATIOS FOR 46 dB SYSTEM S/N

a technique for selecting the minimum system signal level, we need now to consider the maximum signal level (S2, S4, Figure 1) which is required to offset the system losses and maintain this required minimum.

Trunk/Bridger Input Level

Outlined in Figure 5 is a two-way trunk bridger with one output feeding signals to a fully loaded two-way feeder line, followed by one line extender. If we define a total system with the characteristics as shown:

Trunk amplifiers = 80
Feeder amplifiers = 320
N.F. (Trunk/feeder) = 8 dB

we then find by referring to Figure 3 that the minimum signal level must be +21 dBmV for a feeder S/N of 47 dB. This is the minimum level a signal may decrease to before being amplified.

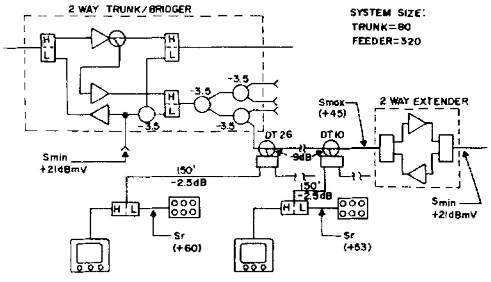

FIG.5 RETURN FEEDER SIGNAL LEVELS — FIRST EXTENDER

This S1 level, referred to as S_{min} in Figure 5, is inside the trunk/bridger amplifier since this is its lowest level point. The signal required at the return extender output (S_{max}) to produce +21 dBmV at the bridger summation point (S_{min}) may be calculated by considering the following:

S_{max} = + 21 + system loss = 45 dBmV

Where system loss = 10.5 (bridger combining loss)
8.0 (Σ directional tap thru losses)
5.5 (Σ cable loss in extender line,
24.0 dB Total 30 MHz)

Additionally, the required return levels at subscribers A, B (Sr) may be calculated since:

Sr A = + 21 + system loss = +60 dBmV

Where system loss = 10.5 (bridger combining loss)
26.0 (DT 26 subscriber drop loss)
2.5 (drop cable loss, 30 MHz)
39.0 dB Total

Sr B = + 21 + system loss = +53 dBmV

Where system loss = 10.5 (bridger combining loss)
4.5 (Σ directional tap thru losses)
4.5 (Σ cable loss in extender line, 30 MHz)
10.0 (DT 10 subscriber drop loss)
2.5 (drop cable loss)
32.0 dB Total

Succeeding Line Extender Levels

Calculation of succeeding amplifier levels, Figure 6, follows the same rules as the first extender. For example:

S_{max} = + 21 + system loss = +34.5 dBmV

Where system loss = 8.0 (Σ directional tap thru losses)
5.5 (Σ cable loss in extender line,
13.5 dB Total 30 MHz)

Sr A = + 21 + system loss = +49.5 dBmV

Where system loss = 2.5 (drop cable loss)
26.0 (DT 26 subscriber drop loss)
28.5 dB Total

Sr B = + 21 + system loss = +42.5 dBmV

Where system loss = 2.5 (drop cable loss)
10.0 (DT 10 subscriber drop loss)
4.5 (Σ directional tap thru losses)
4.5 (Σ cable loss in extender line,
21.5 dB Total 30 MHz)

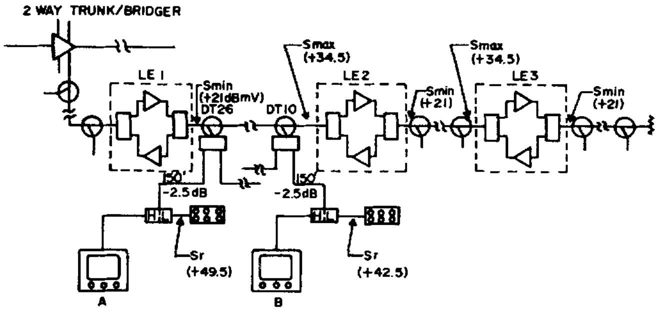

FIG. 6 RETURN FEEDER SIGNAL LEVELS - SUCCEEDING EXTENDERS

As will be noticed, the required system levels above are 10.5 dB lower than those shown in Figure 5. This additionally means that the required extender gain is 10.5 dB lower; this would be true for all succeeding extenders since this difference is due to the absence of bridger combining losses. Operating the feeder amplifiers at two different levels as indicated in Figures 5 and 6 would yield the system design improvements shown below:

1. Operation of succeeding line extenders at a reduced level for improved distortion characteristics. For example, feeder cross modulation for a three amplifier cascade would be:

   -67 @ +45.0 (LE1)
   -88 @ +34.5 (LE2)
   -88 @ +34.5 (LE3)
   $= -67 \oplus -88 \oplus -88 = -65.5$ dB Total

   (Where output capability of each amplifier equals +50 dBmV for -57 dB cross modulation, 2 channels.)

2. The use of a high gain (24 dB) return amplifier in the first extender position, and lower gain (13.5 dB) return amplifiers in succeeding extender positions, which should result in a cost saving.

The removal of the last (LE3) succeeding return amplifier for cost reduction is tempting. However, when consideration is given to the increased source levels required from the subscriber modulators (Sr) to maintain an S_{min} of +21 dBmV at the next extender (LE2), the idea may become less appealing. For example, the return level required at a subscriber terminal feeding into the first directional tap output of LE3 without a return amplifier in this position may be found simply by adding the succeeding amplifier gain requirement of 13.5 dB to the level at the same relative position shown by subscriber A (Figure 6), which would be:

Sr A + 13.5 = 63.0 dBmV

Subscriber Interference

Referring back to Figures 5 and 6 we note that the subscriber return levels (Sr) are quite high. This is especially true at subscriber A in Figure 5 where a +60 dBmV is required to produce +21 dBmV at the bridger. While it is true that future subscriber transmission of "video quality" return signals will not be as frequent as will transmission of "data quality" signals (which could be sent at a lower level), many video requirements in the areas of security surveillance, schools, hospitals and business already exist and should therefore be considered in system planning.

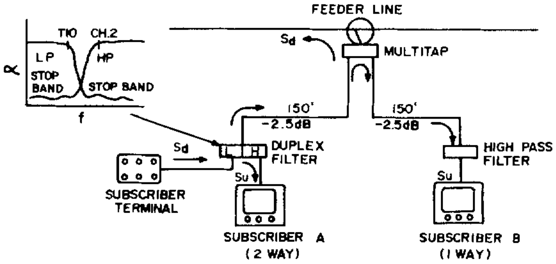

FIG. 7 POTENTIAL SUBSCRIBER INTERFERENCE PATHS

Figure 7 shows a subscriber interface connection frequently used in one-way systems. The arrangement has been modified to provide two-way capacity to subscriber A. The principal signal flow paths are indicated by directional arrows and designated S_D for "desired signal", with the undesired signal designated as S_U. Consider first the sub-band signal being transmitted from the terminal. This signal in the desired mode passes thru the duplex filter, drop cable, multitap, directional coupler and back onto the coaxial cable in the reverse direction due to the steering action of the directional coupler. Two additional paths are available however. The first is thru the duplex filter, attenuated by the high pass filters stop band characteristic, and into the "A" subscriber's TV set. The second path is thru the multitap, attenuated by its port to port isolation characteristic, 300 ft. of drop cable and into subscriber B's TV set.

Signals emanating from the subscriber reverse modulator which are within the pass-band of the high pass section of the duplex filter (i.e. harmonics of the sub-band carrier or other spurious) will be attenuated by the stop band characteristic of the low pass section of the duplex filter and then directly into the "A" TV set, and by way of the multitap into the "B" TV set also. Table II lists the frequency spectrums of sub-band signals whose 2nd and 3rd harmonic products fall within the standard TV channel bands. Under the heading of "known sources" are listed a few of the more commonly used return signal sources with the resultant I.F. beat product tabulated. Picture quality tests (1) have shown that beats of this type should be at least 50 dB below the desired carrier to prevent visual interference.

TABLE II

POTENTIAL SUBSPLIT SUBSCRIBER INTERFERENCE SPECTRUM

VIEWING FREQUENCY(MHz)	IN-BAND HARMONIC SPECTRUM (MHz)	KNOWN SOURCE (MHz)	VIDEO BEAT FREQUENCY (MHz)
54-60 (CH.2)	27-30 (2nd)	28.5 (T10)*	+1.75
	18-20 (3rd)	19 (T9)	+1.75
60-66 (CH.3)	30-33 (2nd)	30.25(SC5)	+.75
	20-22 (3rd)		
66-72 (CH.4)	33-36 (2nd)		
	22-24 (3rd)	22.5 (T9)*	+.25
76-82 (CH.5)	38-41 (2nd)		
	25.3-27.3 (3rd)		
82-88 (CH.6)	41-44 (2nd)		
	27.3-29.3(3rd)	28.5 (T10)*	+2.25

* INVERTED CARRIER

Table III tablulates the potential harmonic interference bands when using the mid-split return system. There are many terminal frequencies other than those listed which may have interfering harmonics, but it is felt by the author that if appropriate design precautions are taken to provide basic spurious protection they will not generally present a problem.

TABLE III

POTENTIAL MIDSPLIT SUBSCRIBER INTERFERENCE SPECTRUM

VIEWING FREQUENCY (MHz)	IN-BAND HARMONIC SPECTRUM (MHz)	KNOWN SOURCE (MHz)	VIDEO BEAT FREQUENCY (MHz)
174-180 (CH.7)	87-90 (2nd) 58-60 (3rd)		
180-186 (CH. 8)	90-93 (2nd) 60-62 (3rd)	61.25 (CH.3)	+2.50
186-192 (CH. 9)	93-96 (2nd) 62-64 (3rd)		
192-198 (CH. 10)	96-99 (2nd) 64-66 (3rd)		
198-204 (CH. 11)	99-102 (2nd) 66-68 (3rd)	67.25 (CH.4)	+2.50
204-210 (CH. 12)	102-105 (2nd) 68-70 (3rd)		
210-216 (CH.13)	105-108 (2nd) 70-72 (3rd)		

Table IV presents what can only be labeled as "typical" subscriber interference levels, since the magnitude of the undesired frequencies and exact isolation of taps and filters can only be estimated.

If we assume that most return modulators or data transmitters will have a spurious rejection of at least 60 dB, and port to port isolation of a reasonably good tap to be 25 dB, then we are left with the duplex filter, which should be specified as having a stop band attenuation of at least 40 dB. These specifications are reflected in Table IV, and the resultant interference levels are shown. For purposes of analysis only, one frequency of the in-band and one frequency of the stop band type are used, since all interfering frequencies will be in one of these two categories.

TABLE IV

TYPICAL SUBSCRIBER INTERFERENCE LEVELS

SUBSCRIBER A ORIGINATION FREQUENCY (MHz)	ORIGINATION LEVEL (dBmV)	TRANSMISSION LOSS (dB)		INTERFERENCE LEVEL (dBmV)	
		A	B	A	B
28.5 (T10)	+60	-40	-30	+20	$\boxed{+30}$
57.0 (T10) 2nd HARMONIC	0	-40	-70	$\boxed{-40}$	-70

Refering again to Table IV and Figure 7, we find that the 2nd harmonic of T10 appears at the return modulator A output at a level of 0 dBmV. This in-band spurious signal will pass thru the duplex filter with an attenuation of 40 dB and then be presented to the "A" TV set at a level of -40 dBmV. When a channel 2 desired signal is being received at a level of +6 dBmV, this spurious signal appearing at an in-band level of -40 dBmV will permit only a 46 dB signal to beat ratio - which is not adequate.

In cases such as this where a modulator level of +60 dBmV is required, either another frequency must be chosen which will not have in-band harmonics or else special filtering techniques must be employed (i.e. modulator band pass filter).

The propagation of out of band signals from modulator A will now be considered. These signals are typified by the T10 (28.5 MHz) frequency shown in Table IV. This signal will appear at the TV "A" input, attenuated 40 dB by the duplex filter, at a level of +20 dBmV. Additionally it will appear at the TV "B" input, attenuated by the drop cable loss and multitap isolation, at a level of +30 dBmV. The exact interference tolerance level of TV sets to sub-band frequencies is not well defined and it would therefore be a wise precaution to use matching transformers with built in high pass filters in any two-way installation where high level signal transmission may be necessary.

No attempt will be made to present an analysis of the additional beat problems caused by L.O. radiation or multi-channel set top converters(2), since it is felt that the use of protective filters at the TV set input can correct the majority of beat problems relating to return transmission.

System Temperature Stability

As a final point for consideration in the return feeder system, the effect of temperature on system levels should be examined. For purposes of analysis the following general assumptions will be made:

1. Flat losses (i.e. directional couplers, splitters, combining networks) are constant and not effected by temperature variations.
2. The return signal source itself is not effected by temperature variations.
3. Level variations due to subscriber drop cable temperature variations are not more than ±.2 dB at return signal frequencies (5-30 MHz).

If we additionally assume a feeder system of the characteristics shown:

maximum line extender cascade = 3
total cable length = 3,640' of .412
total cable attenuation @ 30 MHz = 21.8 dB
maximum temperature excursion = -40° - $+140^{\circ}$ F.

then the total signal level variation at 30 MHz presented to the return trunk/bridger amplifier input, due to temperature variations, would be: (Figure 8)

$$21.8 - [21.8 \times (1 + 0.0012\,(T-68)) - .2] = +3.0 \text{ dB} @ -40^{\circ}$$
$$-21.8 + [21.8 \times (1 + 1.0012\,(T-68)) + .2] = -2.1 \text{ dB} @ +140^{\circ}$$

Since this change is distributed over 3 amplifiers and 4 spans of cable the amount of level correction needed in each return line extender would be:

$$+2.1/3 = +.7 \text{ dB} @ +140^{\circ}$$
$$-3.0/3 = -1.0 \text{ dB} @ -40^{\circ}$$

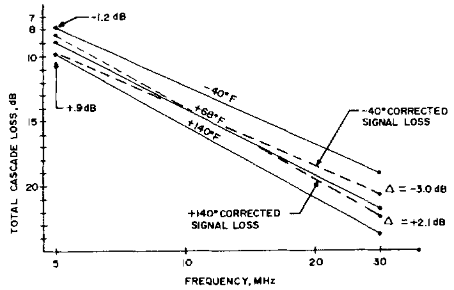

FIG. 8 THERMAL CHARACTERISTICS OF THREE EXTENDER FEEDER LINE CASCADE

If the amount of flat amplitude correction actually applied to each return extender is limited to: (Figure 8)

+.5 dB @ +140°
-.7 dB @ -40°

then the total temperature excursion at the return trunk/bridger input will be less than ± 1 dB (worst case, 5-30 MHz). Individual amplifier level corrections of this magnitude are readily achieved with internal thermal gain control techniques and will serve to maintain the feeder system well within design limits.

Summary

A discussion of system design considerations pertaining to the distribution portion of a bi-directional CATV system has been presented, with the object of giving the designers of both new and existing cable systems: 1) some areas where performance trade-offs may be made, 2) a few of the potential problems, and 3) some of the solutions.

* * * *

APPENDIX

I. Calculated from the following:

Extender increase = 150 amplifiers
Maximum directional taps per amplifier = 7
Maximum number of subscribers per tap = 4
Total subscriber increase = 150 x 4 x 7 =4,200

II. Return trunk system operating characteristics:

System definition:

Maximum number of trunk amplifiers = 90
Maximum trunk cascade length = 20
Average trunk spacing loss (-3.4 flat, -6 cable, -3.5 bridger combining loss) = 13 dB
Trunk amplifier noise figure = 8 dB
Trunk amplifier cross modulation at operating level (4 channels @ +35 dBmV) = -91

System Performance:

Cross modulation = $(-91 + 20\ \text{Log}_{10}\ 20) = -65$ dB
S/N = $+22 - (-59 + 8 + 10\ \text{Log}_{10}\ 90) = 53.5$ dB

Combined Trunk/Feeder Performance:

Cross modulation = $(-65) \oplus^{*} (-65.5) = -59$ dB
S/N = $(47) \oplus (53.5) = 46$ dB

Round Trip System Performance:

Cross modulation = $(-59) \oplus (-59) = -53$ dB
S/N = $(46) \oplus (46) = 43$ dB

*Denotes logarithmic addition.

* * * *

REFERENCES CITED:

1) Walding, G., "Spectrum Pollution and the Set Top Converter", TV Communications, Volume 8, pp. 142-148, July, 1971.

2) Levine, N., "The Dilemma of Mixed Systems", Proceedings of 1972 NCTA Convention, Chicago, Illinois.