# COMPOSITE SECOND ORDER DISTORTIONS

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*ABSTRACT*

*The last few years have seen cable television technology leap from 300 MHz, thirty-five channel capacity to 450 MHz, sixty channel capacity and beyond. New technologies which use two amplifiers in the post amplifier stage are now being used to reduce the level of composite triple beat in extended bandwidth systems. The two amplifiers are arranged in parallel or in a feedforward configuration and reduce post-amplifier composite triple beat levels by 5 dB and 18 dB respectively.*

*Test results are presented which show that second order distortion can be the limiting distortion in a system carrying more than fifty channels.*

*An analysis is then performed to confirm that second order distortion should be of very real concern to designers of both amplifiers and systems. This analysis also shows that active equipment using parallel or feedforward post amplifiers give a disappointing improvement in second order distortion performance.*

## INTRODUCTION

Many cable television systems are now rebuilding or upgrading their networks in order to have the capacity to carry extra channels. These extra channels may have to be carried in order to meet franchise commitments, or in order to generate greater revenue for the system.

Carrying more channels on a system causes two basic technical problems: an increase in intermodulation distortion and greater cable loss because the added channels are usually carried at higher frequencies. Due to the large economic advantages obtained by reusing existing cable, amplifiers with high gain and high output capability are desirable. In order to meet these two requirements new amplifier technologies such as feedforward and parallel-hybrid amplifiers have been developed. In addition, various new headend technologies are sometimes used to improve system performance. Two commonly used examples of these are incrementally related carrier (IRC) frequency assignments and scrambling systems which as a side benefit reduce distortion levels in the system.

These technologies are all designed to reduce the level or the effects of composite triple beat (CTB), the generally accepted limiting distortion in a cable television system.[1] Feedforward and parallel-hybrid technologies are typically used in post-amplifiers and provide some 18 dB and 5 dB improvement respectively in post-amplifier CTB. In an IRC system, CTB falls precisely on the video carrier frequency. The subjective degradation of picture quality is reduced, although the CTB level is unchanged. It is generally considered that IRC technology permits a 3 to 5 dB increase in amplifier output levels.[1] Scrambling systems used to provide security for pay channels or for tiered channels often use techniques such as suppression of synchronization pulses, or alteration of video levels. One such technique, called sync suppression and active video inversion (SSAVI), reduces the CTB level by at least 10 dB if all channels are scrambled, and by a lesser amount if only some channels are scrambled.[2]

Cablesystems Engineering has performed subjective and objective tests on cascades of amplifiers fed by an operating system which uses IRC and has 30 out of 52 channels SSAVI scrambled. Cascades of 16 feedforward trunk amplifiers, 16 conventional trunk amplifiers and a combination of both cascades were all tested. The limiting distortion with various system configurations is shown in Exhibit 1, where it can be seen that CTB was not always the limiting distortion and that composite second order beats (CSB) tended to be the limiting distortion in many cases. This paper will examine why the technologies which give a significant improvement in CTB give a somewhat disappointing improvement in CSB and will propose possible solutions to CSB problems.

## CTB IMPROVEMENTS WITH NEW TECHNOLOGIES

Improvements in CTB achieved with new technologies have been well researched and documented. This section will briefly summarize previous work in this area in order to highlight the differences between improvements in CTB and CSB.

EXHIBIT 1: LIMITING NON-LINEAR DISTORTION USING VARIOUS HEADEND TECHNIQUES AND AMPLIFIER TECHNOLOGIES AS TESTED BY CABLESYSTEMS ENGINEERING USING 52 CHANNEL (400 MHz) LOADING

| Amplifier Technology | IRC Comb | Modulation | Limiting Distortion |
|---|---|---|---|
| Feedforward (6dB O/P slope) | off | NTSC | CSB |
| | off | NTSC/SSAVI | CSB |
| | on | NTSC | CSB |
| | on | NTSC/SSAVI | CSB |
| Conventional (flat O/P) | off | NTSC | CTB |
| | off | NTSC/SSAVI | CTB |
| | on | NTSC | CTB |
| | on | NTSC/SSAVI | CTB |
| Feedforward and Conventional | off | NTSC | CSB |
| | off | NTSC/SSAVI | CTB |
| | on | NTSC | CSB |
| | on | NTSC/SSAVI | CSB |

Feedforward and parallel-hybrid technology is analyzed first. A conventional station with a single hybrid post-amplifier is used to determine reference distortion levels. Stations which have the same gain as the conventional station but which have parallel-hybrid or feedforward post-amplifiers can then be analyzed to determine CTB improvements by comparing their CTB performance with the reference conventional station performance. Block diagram models of these three amplifier types are shown in Exhibit 2. Output levels of preamplifier and post-amplifier hybrids are shown in Exhibit 3.

EXHIBIT 2: TYPICAL GAINS AND LOSSES INTERNAL TO A CONVENTIONAL, FEEDFORWARD AND PARALLEL-HYBRID STATION

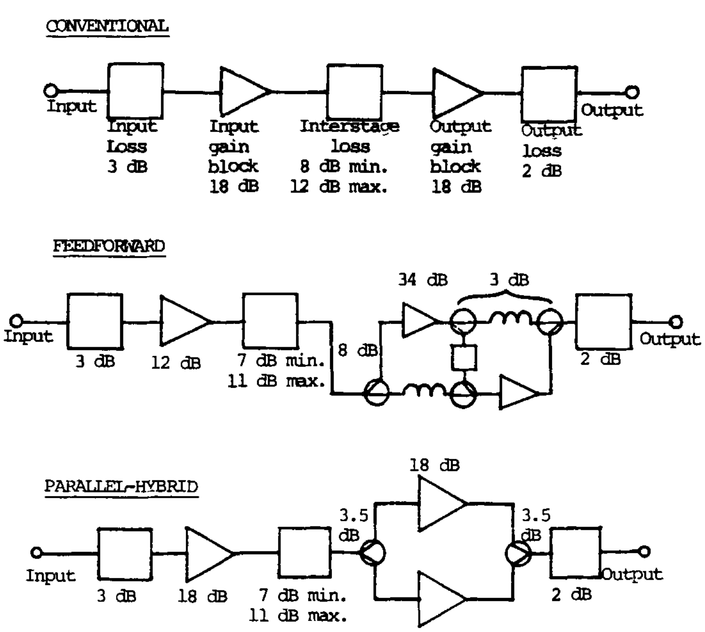



EXHIBIT 3: OUTPUT LEVELS IN dBmV OF THE HYBRID AMPLIFIERS IN EXHIBIT 2 FOR A STATION OUTPUT LEVEL OF 34 dBmV

| Station Type | I/P Hybrid Level AGC @ max | AGC @ min | O/P Hybrid Level |
|---|---|---|---|
| feedforward | 20 | 24 | 39 |
| conventional | 26 | 30 | 36 |
| parallel-hybrid | 26 | 30 | 33.5 |

If a standard hybrid amplifier CTB spec of -86 dBc at a flat output level of +34 dBmV for 52 channels is assumed then the performance of the three stations can be compared by calculating CTB levels generated by the input and output amplifiers as is shown in Exhibit 4. It should be noted that the CTB level for the output hybrid amplifier has been improved to take into account its sloped output level. The CTB contribution of the input hybrid amplifier has been calculated twice, at the two extremes of a 4 dB range in station input level.

EXHIBIT 4: CTB RATIOS FOR THE THREE STATIONS IN EXHIBIT 2

| Amplifier | AGC gain | CTB (dBc) I/P | O/P | Station |
|---|---|---|---|---|
| feedforward | max | -114 | -103 | -100.8 |
| | min | -106 | -103 | - 98.4 |
| conventional | max | -102 | - 85 | - 83.9 |
| | min | - 94 | - 85 | - 82.4 |
| parallel-hybrid | max | -102 | - 90 | - 88.1 |
| | min | - 94 | - 90 | - 85.8 |

Significant station CTB improvements are achieved using feedforward and parallel-hybrid technologies. These improvements are in the order of 16 dB and 4 dB respectively.

In a rebuild situation, the great appeal of parallel-hybrid and feedforward stations is that they can be configured with higher gains and higher output levels than can conventional stations while still delivering the same CTB performance. Stations with gains of 26 and 30 dB can be constructed using amplifier stages with higher gain. If a preamplifier with greater gain is used, then for a given station output level the CTB level will remain constant. If a post-amplifier with greater gain is used then the preamplifier will contribute less CTB for a given station output level.

Frequency assignment techniques such as IRC do not effect the level of CTB but are designed to make most third order beats caused by offending video carriers fall precisely on the video carrier frequency of the victim channel.[3] This can alter the victim channel's video carrier level by a small amount, but the effect of this on picture quality is negligible. Another similar frequency assignment technique is harmonically related carriers (HRC). With HRC, all in-band beats formed by video carriers fall precisely on the video carrier frequency of a channel. An HRC system however, can not usually be used in a rebuild as HRC frequency assignments are non-standard and are incompatible with many television sets and converters.

The SSAVI scrambling system is comprised of two elements. First, the horizontal synchronization pulses are suppressed and second, the video information is inverted when its average level is less than 50 IRE units. Both of these elements reduce the average RF level in a channel and thus reduce the average level of a beat created by one or more scrambled channels.

In a system which is undergoing a rebuild in order to increase its channel capacity, there are likely already a large number of channels which are non-scrambled. These unscrambled channels form part of a basic service offering. In a rebuild it may be unwise from a marketing viewpoint to scramble these channels, but there is no reason why extra channels could not be scrambled, as they would likely form part of a pay service, or at least part of a more expensive tier of service.

If all channels on the system were SSAVI scrambled, approximately a 10 dB reduction in CTB level should be expected. Significant reductions in CTB level should also be expected even if less channels are scrambled. For example, if all channels from 54 MHz to 260 MHz are unscrambled and all channels from 260 MHz to 400 MHz are scrambled, greater than 5 dB reduction in CTB can be expected.

## SYSTEM TEST RESULTS

As briefly described in the introduction, a test was conducted to determine the effects of low distortion post-amplifiers, IRC and SSAVI.

The conventional, feedforward and combined cascades were tested with the four combinations of IRC on and off and SSAVI scrambling on and off. Selected victim channels were viewed as amplifier output levels were adjusted until it was determined that barely perceptible distortion was visible on the victim channel. Objective tests were then made at that level. CSB was the distortion which limited output levels in the cascade under several conditions.

The test results have been examined in an attempt to determine why CSB was predominant. First, the reduction in beat level achieved by using a feedforward post-amplifier was examined. The reduction in CTB and CSB achieved by using a feedforward post-amplifier is shown in Exhibit 5, where it can be noted that for any signal format, significantly less feedforward improvement is obtained for CSB than for CTB.

The effect of an IRC frequency assignment as compared to a standard assignment where output frequencies are not locked to a comb was subjectively analyzed. The addition or removal of IRC from the system did change the pictures when

EXHIBIT 5: IMPROVEMENT IN CTB AND CSB OF A FEED-FORWARD STATION OVER A CONVENTIONAL STATION

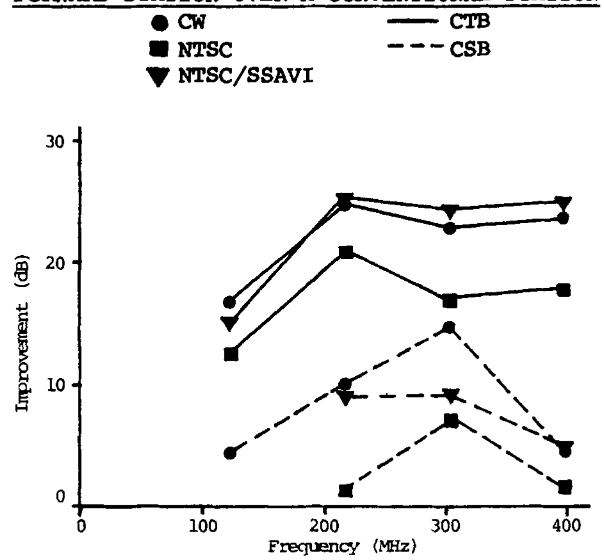
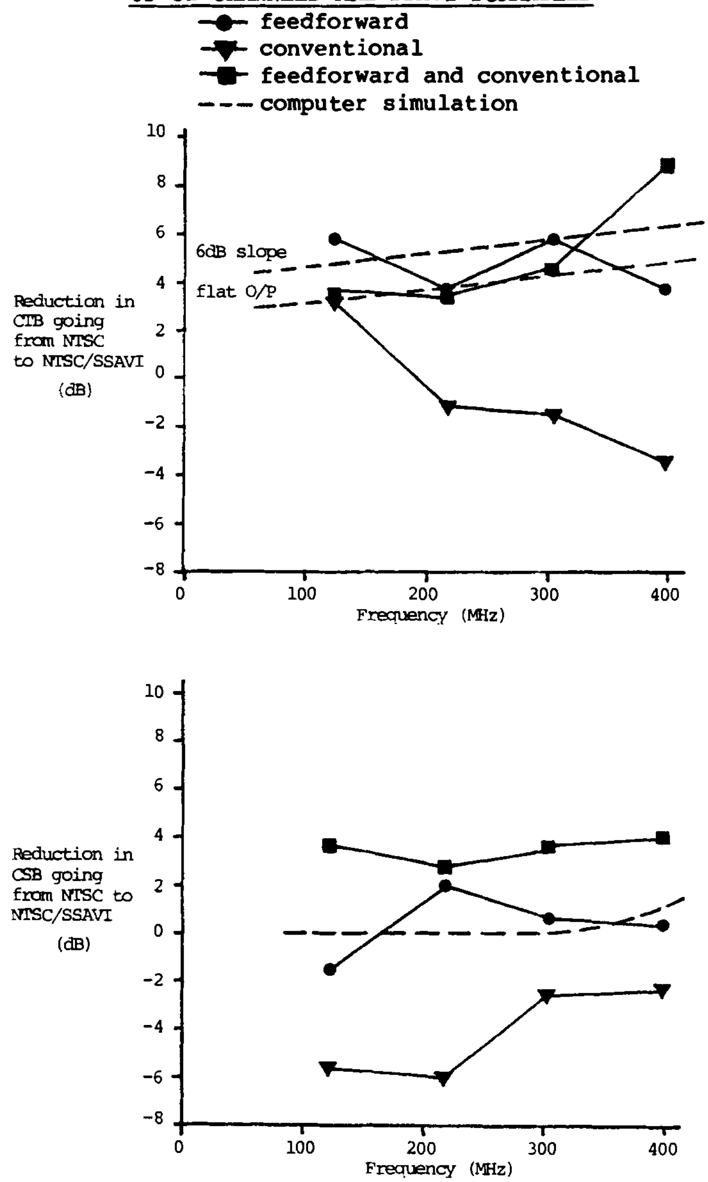



EXHIBIT 6: IMROVEMENTS IN CTB AND CSB WHEN 30 OUT OF 52 CHANNELS ARE SSAVI SCRAMBLED



distortion, particularily CTB, was present. However, no significant improvement in picture quality was evident when IRC was added to the system. This result conflicts with previously published work and may be due to some peculiarity in the operating system, such as the large number of character generator channels.

The effect of signal format on CTB and CSB was analyzed by comparing the difference in beat levels on a system with NTSC signals and on the system with 30 of the signals SSAVI scrambled. Differences in CTB and CSB levels are shown in Exhibit 6, where it is clear that less improvement due to SSAVI scrambling was measured for CSB than for CTB. The reason for anomalous test results in the conventional cascade is unknown.

## CSB IMPROVEMENTS WITH NEW TECHNOLOGIES

The tests results in the previous section indicate that new technologies give a disappointing improvement in CSB compared with the improvement in CTB. It is interesting to examine why these technologies give less improvement in CSB when compared to CTB.

Using the station models used to compare the effect of different post-amplifier technologies on CTB (see Exhibit 2), an analysis of the effect of these technologies on CSB was conducted. Due to a lack of CSB specifications for hybrids an assumed specification must be used. A CSB specification of -66 dBc at a flat output level of +34 dBmV for 52 channels was considered reasonable. CSB levels for preamplifiers and post-amplifiers are calculated and shown in Exhibit 7, where it is clear that the preamplifier is a major contributor of CSB, especially with a feedforward post-amplifier.

EXHIBIT 7: CSB RATIOS FOR THE STATIONS IN EXHIBIT 2

| Amplifier Type | AGC Gain | CSB (dBc) I/P | O/P | Station |
|---|---|---|---|---|
| feedforward | max | -80 | -92 | -79.7 |
| | min | -76 | -92 | -75.9 |
| conventional | max | -74 | -71 | -69.2 |
| | min | -70 | -71 | -67.5 |
| parallel-hybrid | max | -74 | -73.5 | -70.7 |
| | min | -70 | -73.5 | -68.4 |

EXHIBIT 8: IMPROVEMENTS IN CTB AND CSB TO BE EXPECTED BY USING A FEEDFORWARD OR PARALLEL-HYBRID OUTPUT STAGE INSTEAD OF A CONVENTIONAL OUTPUT STAGE

| Amplifier Type | AGC Gain | CTB | CSB |
|---|---|---|---|
| feedforward | max | 16.9 | 10.5 |
| | min | 16.0 | 8.4 |
| parallel-hybrid | max | 4.2 | 1.5 |
| | min | 3.4 | 0.9 |

Improvements in both CSB and CTB achieved by using feedforward and parallel-hybrid post-amplifiers compared to conventional post-amplifiers are shown in Exhibit 8. It is clear that improvement in CSB is much less than that in CTB, due to the significant contribution of the preamplifier hybrid.

As mentioned earlier, in a system with an IRC frequency assignment, most third order video carrier beats fall precisely on the victim channel video carrier frequency. However, no change should be expected in CSB due to the addition of IRC to a system.

If all channels in a system have the same signal format, the effect of a change in signal format on the levels of CTB and CSB can be analyzed fairly simply. Since three channels combine to form a third order beat and only two channels combine to form a second order beat, the change in CSB level would be expected to be two-thirds of the change in CTB level.

In most systems, however, only certain bands of channels would be scrambled. An analysis of CTB and CSB levels under these conditions was conducted. Television channels modulated with an average video level of 30 IRE units were modelled. The levels of individual third order and second order beats were predicted as the relative phases of the video information were varied randomly. Time average discrete beat levels were then established. All individual third order and second order beats falling on selected victim channels were classified according to offending channel signal format and level. Expected CTB and CSB levels were then determined by adding individual beats on a power basis. Using this method, improvements in CTB and CSB levels were predicted for the channel line-up described earlier, where all channels from 260 MHz to 400 MHz were SSAVI scrambled. Predicted reductions in CTB and CSB are shown in Exhibit 6, where it is clear that significant CTB improvements can be expected with SSAVI scrambling, while very little CSB improvement can be expected. It should be noted that this analysis assumed that the relative phase of the video information on offending channels was random. If many, but not all channels have common sync pulse sources, then the effects on beat levels and picture quality may be detrimental.

## POSSIBLE SOLUTIONS TO CSB PROBLEMS

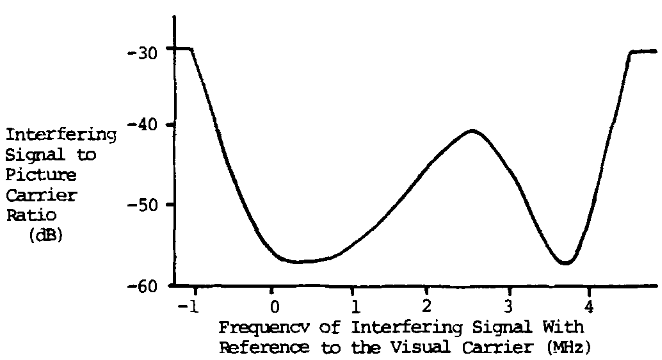
An improvement in post-amplifier technology can achieve excellent improvement in CTB levels because the post-amplifier in a conventional amplifier is the major contributor to CTB. However, when considering CSB, the preamplifier can be a major contributor, especially when low distortion post-amplifiers are used.

In order to reduce the CSB level from the preamplifier, three approaches could be taken. First, hybrid amplifiers with better CSB performance could be used as preamplifiers. Second, preamplifier hybrids could be arranged in a parallel-hybrid or feedforward configuration to reduce their CSB contribution. Third, hybrids could be tested for critical parameters such as noise figure, CSB and CTB levels and selected for various uses. For example, in feedforward amplifiers, preamplifier hybrids with good noise figure and CSB characteristics could be used, post-amplifier hybrids with good CTB characteristics could be used and other hybrids could be used as error amplifiers.

Amplifier output slope has a significant effect on CSB levels. The CSB high frequency levels of an amplifier operating with 6 dB output slope will be approximately 7 dB lower than the CSB levels of a similar amplifier with flat output levels.[4] At the low end of the frequency band, CSB levels will be higher with sloped outputs than with flat outputs. However, this may not be a problem because hybrid amplifiers have better second order distortion performance at lower frequencies.

The IRC frequency assignment was designed to mask the effect of CTB by making it fall precisely at a video carrier frequency. Using this frequency assignment or even with a standard unlocked frequency assignment, second order beats formed by the summation of offending carrier frequencies fall 1.25 MHz above a victim video carrier frequency. As can be seen from Exhibit 9, this is a critical area of a video channel.

EXHIBIT 9: CURVE SHOWING THE RELATIVE SENSITIVITY OF A VICTIM CHANNEL TO AN INTERFERING SIGNAL AS A FUNCTION OF FREQUENCY




It would be more desirable to have these beats fall 2 to 3 MHz above the video carrier frequency. In order to accomplish this, a non-standard frequency assignment could be used. For example, channels above 300 MHz could be lowered by 1 MHz from their standard frequency assignment, while all channels below 300 MHz would remain on their standard frequencies. This would sacrifice one channel which would only have 5 MHz of spectrum from 300 MHz to 305 MHz. This spectrum could be used for other purposes such as modified video transmission or data transmission. The frequencies of various second and third order beats generated using this non-standard frequency assignment have been analyzed and compared to the frequencies of beats generated using a standard frequency assignment. The results of this analysis are shown in Exhibit 10.

EXHIBIT 10: NUMBER OF SECOND AND THIRD ORDER BEATS FALLING ON SAMPLE VICTIM CHANNELS WITH AND WITHOUT FREQUENCY OFFSETS (400 MHz SYSTEM)

| Frequency Assignment | Carrier Frequency | CTB 0MHz* | CSB 1.25MHz* | CSB 2.25MHz* |
|---|---|---|---|---|
| Standard | 397.25 | 565 | 16 | - |
| | 301.25 | 806 | 8 | - |
| | 217.25 | 827 | 3 | - |
| Offset | 396.25 | 401 | 3 | 13 |
| | 306.25 | 401 | 0 | 9 |
| | 217.25 | 567 | 3 | 0 |

*NOTE: These frequencies refer to the beat frequency relative to the victim channel frequency.

Note that on the highest channel, 16 second order beats fall 1.25 MHz above the video carrier frequency with a standard assignment, while with a non-standard assignment only 3 beats fall on the same frequency. The other 13 beats fall at a less critical frequency 2.25 MHz above the video carrier frequency. Assuming power addition of beats and neglecting the beats falling 2.25 MHz above the video carrier frequency, then a 7.3 dB improvement in CSB level can be achieved using this non-standard frequency assignment. This was accomplished at the cost of one lost video channel and possible tuning problems with existing converters. In a rebuild situation these tuning problems may be minor, as existing converters may not tune beyond 300 MHz in any case.

It should also be noted in Exhibit 10 that the non-standard frequency assignment will give a minor improvement in CTB level. If all third order beats not falling on the video carrier frequency are neglected, than a 1.5 dB improvement on the highest channel could be expected using this non-standard frequency assignment.

The frequency offset of channels between 300 MHz and 400 MHz should be viewed only as an illustration of the potential benefits which could be realized with frequency offsets. No attempt was made to determine an optimum frequency assignment, and the effect of changing the frequencies of beats falling at the low end of the frequency spectrum may be unacceptable. However, it does appear that non-standard frequency assignments may provide a significant improvement in CSB levels and some improvement in CTB level as well.

## CONCLUSIONS

A number of new technologies have been developed in order to reduce the level or the effects of CTB. Test results have been presented which indicate that feedforward post-amplifiers, power doubling post-amplifiers and SSAVI scrambling do in fact reduce CTB levels as expected. The expected improvement in picture quality obtained by using IRC frequency assignments was not observed during these tests.

Test results have been presented which demonstrate that CSB can be the limiting intermodulation distortion in cable systems carrying over 50 channels. This is in large part due to the fact that the technologies which have been developed to improve CTB performance provide much less CSB improvement. Further work should be done in an effort to reduce the levels or the effects of CSB.

Promising areas of development include improving preamplifier CSB performance to reduce station CSB levels and further investigating non-standard frequency assignments in an effort to reduce the impairment caused by CSB.

## ACKNOWLEDGEMENTS

The authors would like to express their thanks to the CTRI for their support of the research documented in this paper.

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