SIMULTANEOUS, QUASI SYNCHRONOUS, SYNCHRONOUS, - BROADCASTING

A discussion on the subject from the perspective of David Cahill - who first encountered the concept in working systems in 1967.

CONTENTS

1 INTRODUCTION

It is not the intention here to go in to great technical and academic detail, rather, this paper is directed to those who have the practical requirement for wide area cover PMR using Quasi and Fully Synchronous transmissions. There are other sources of information elsewhere in the many papers that have been published over the years, please see paragraph 8.

2 WHAT IS IT?

In the context of a multiple base-station Private Mobile Radio system 'simultaneous' refers to the practice of sending a signal - usually voice - to a 'mobile' receiver via multiple transmitters. The alternative is to use just one of the base station transmitter – 'site select'. Within the PMR community the term also has an implicit expectation of 'synchronization' which is not readily apparent to the novice - and indeed to some 'experts'. It is this 'synchronization' which used to cause much heartache.

3 WHY USE IT?

In order to cover a wide geographical area using low power transmitters. The alternative is to put one 'big' transmitter in the middle of the area and blast away; this approach is becoming increasingly antisocial.

4 SOME OF ITS HISTORY.

When PMR systems evolved from the use of 'big' transmitters to the use of 'smaller' units two problems had to be overcome. The first, that of the audio beat (in the mobile) between transmitter carriers; the second, that of the audio distortion caused by the mixing of multiple, out of phase, signals. Around this time RF channel spacing was in the order of 50kHz with transmitter frequencies drifting around a mean by several hundred Hz; and the signals to the transmitters travelled over radio links or fixed (a DC path over copper) land lines. Overcoming these two problems was not technically taxing. With the RF spectrum bandwidth available, it was possible to move the individual transmitter frequencies such that the carrier was within the RF bandwidth of the mobile but the beat was outside its audio range. For example, in a three transmitter system off-setting the transmitter frequencies by +9kHz and –9kHz and –3kHz would not result in an audible beat - provided that the mobile audio response was adjusted to reject the nominal 6kHz interaction of two of the carriers. This method overcame the first problem. The second was simpler, calculation or measurement of the time delay over the line/link circuit enabled the fitting of suitable audio delay circuits in individual line/links to equalize the delay and 'synchronize' the audio mixing in the mobile. Another issue related to the audio circuits associated with the 'reversal' of the audio path - see section 5.2c – was easily overcome by careful installation. However, in time, the RF spectrum began to be squeezed and it was not possible to continue using spaced carrier operation.

The next stages in the evolution of Simulcast were responses to the narrowing spectrum and the change from DC to AC land lines; and the introduction of FFSK data-over-radio called for more accurate equalisation of carriers and their modulation content. The two original problems had to be addressed once more. The solution to the first problem - that of the carrier beat - seemed to be a simple matter of putting the transmitters all on (nominally) the same frequency, but giving birth to a maintenance nightmare. The resulting sub audio beating of the carriers had to be closely controlled to keep the beats away from the syllabic rate of speech (6Hz to 15Hz) to avoid almost total speech unintelligibility. High stability oscillators were introduced to keep the transmitter carriers within a few Hz or, at the worse, a few tens of Hz; however, even measuring the frequency was problematic - not that equipment was not available to enable accurate measurement - but the economics of supplying field technicians with this equipment strained many budgets.

The nature of the second problem - that of equalizing the delay - did not change overnight. The introduction of AC lines was gradual and, initially, had impact on the methods of controlling the system (with the removal of the ability to use DC switching) and of course systems using radio links were not affected at all. However, the squeeze in spectrum was also reducing the availability of radio link frequencies so more and more systems were using land lines. The AC lines also introduced a continuously varying phase relationship end to end due to the unlocked nature of the encoding and decoding oscillators used by the Frequency Division Multiplexers on the line network. Phase locking equipment was soon developed to remove this problem, but the huge variation in circuit distortions led to great difficulty in matching the circuit delays across the whole of the audio bandwidth, but again networks were developed to overcome this problem too. (See bibliography 8.1.b & c)

A significant impact on systems came when the telephone/line companies changed to digital multiplex systems on their networks and began to use dynamic switching to re-route the end to end connections of 'dedicated' lines. A more insidious problem also became apparent, that of slowly varying end to end delay, caused by the flexible buffers in the digital multiplex incorporated to allow slight differences in clocking speeds across the network. Various methods were used, and proprietary equipments made available, to periodically automatically measure and set the delay. These sub-systems gave some protection against the re-routing problem and slowly varying delay; generally they worked by measuring the time taken for a signal to go from the line node to a co-sited monitor receiver on mobile frequency. This process was performed on each base transmitter in turn and the collected data used to determine the relative delays over the different circuits. The main failing in these systems was the need for the monitor receiver to be within the range of each of the base transmitters and the susceptibility of the system to outside interference. Then the Global Positioning System arrived and a synchronized time reference became available - the story continues with today's situation and practice.

The signal transmitted to the mobile was not the only element of the operator/mobile communication link to be affected. Signals inbound to the dispatcher from the mobile could also be of the multiple path nature. It will be apparent to the uninitiated in synchronous systems that having provided communications over a wide geographical area using several base transmitters there is a requirement for several base receivers to service the signals returning to the dispatcher from the mobile. These audio signals also suffer from being out of phase, however, initially these signals were simply mixed together pending the development of signal selection equipment. Signal selection – or Voting – is the process whereby one (the best!) is passed to the operator and all others are blocked; generally this is achieved in one of two ways: -

- i The base receiver may be configured to generate a Received Signal Strength Indicator (RSSI) which is passed – along with the audio - to the return signal node location where a process of selecting the 'best' RSSI takes place; the expectation being that the 'best' RSSI correlates with the 'best' signal.
- ii The separate audio channels are returned to the node where signal to noise measurements are made and the 'best' signal is passed on.

5 MODERN DAY PROBLEMS

5.1 Maintaining base transmitter frequency.

Modern methods of frequency reference are available at modest cost. It should be recognised that, in the context of a synchronous system, the requirement of carrier frequency is not necessarily that of absolute accuracy - indeed it never has been, provided statutory channel stability is adhered to; the requirement is about the relative frequencies of base transmitters to each other. Most modern base transmitters are built to accept an external reference frequency and many Synchronous Systems use this method to maintain transmitter frequency. Alternatively, there are frequency synthesizers which are referenced to a frequency standard and output the frequency required to drive the transmitter. The actual frequency standard to which the equipment is referenced can be accessed either locally or remotely. Local frequency referencing may take the form of a high stability oscillator referenced to a rubidium source. Remote frequency referencing will use, off-air, a reference maintained by a standards agency and radiated for that purpose; off-air standards range in methodology from that of a specific radiated frequency to that of a periodic pulse such as that which is available from the Global Positioning System.

Current practice suggests that the transmitter frequencies in most UHF (~460MHz) and some high-band VHF (~160MHz) can be synchronous - ie have no offset. The geographical layout and overlap of the contributing transmitters is a determining factor whether synchronous or offset frequencies are used successfully in these frequency bands. At low-band (~70 MHz), due to the longer wavelength, offsets are normally used. The amount of offset (in Hertz) being chosen to avoid any carrier beats interfering with the syllabic rate of speech.

5.2 Audio Parameters

a. Group Delay.

Generally when different frequencies are passed through an analogue circuit they will exhibit different phase changes; this variation in the phase/frequency characteristic is referred to as 'Group Delay'. This would not be a problem if the relative 'distortion' were the same on each circuit; but this is not the case. The characteristic of the distortion alters as filters are tuned and the length of the (analogue) line changes. This distortion may be compensated for by a circuit in the system which is adjusted to equalize the distortion - the distortion was not necessarily removed, each circuit being made to have the same (hopefully) distortion relative to the other circuits. Maintenance engineers use a network analyser linked to equalize the relative distortion on different circuits; once adjusted the system will remain equalized until a filter is retuned or the telephone line re-routed. Whilst this problem still exists its impact is diminishing because the telephone/line companies are increasingly using digital (as against analogue) techniques to transport the signals - the 'tails' (the connection between the line exchange and the synchronous system equipment) remain analogue but the greater part of the line is digital. Over a 'digital' line, whilst the bulk delay is subject to change, the group delay remains substantially constant and does not present a major problem.

b. Intercept Error.

Theoretical extrapolation of the frequency/phase characteristic back to zero frequency and/or zero phase shift may result in the graph not intercepting the axes at the origin (the 0 degrees and 0 Hz point). Any deviation of the curve from the 0/0 point is referred to as an Intercept Error. Intercept errors may be +ve or –ve. Compensation for Intercept Error variation (comparing one circuit with another) may be provided by a wide band phase shift control.

c. Bulk Delay.

The re-routing, which may occur only occasionally and always without notice, or the flexible buffering, re-framing and bit-stuffing processes, contribute to changes in the audio (bulk) delay that degrade the system. There are two manifestations of this process on the perception of the user to system performance. The change may be small in which case the degradation of the system may be slight, but over a period and after several changes the system acquires a reputation among its users as being unreliable and almost unusable; the change may be so subtle and over such a period that none of the users have experienced anything else in this system. Alternatively there may be major and frequent re-routing, the effects can be serious enough to cause the operator to take the system out of service. Both require the regular, and perhaps frequent, attention of the maintenance crew unless automatic compensation is fitted

d. Line Reversal.

This is a less apparent problem that has little to do with the re-routing of lines, except perhaps the analogue tails. It may manifest itself in any system including those using radio links rather than land lines. The problem occurs when the audio signal is inverted in the circuit between the node and the mobile. The distortion in the system can not be compensated for by adjustment of the bulk delay. Historically detection of an inversion in the line was an easy matter of DC continuity checks, today it is not so simple and may cause maintenance crews some grief. This problem does not only occur in the line portion of the circuit, care should be taken that the adjustment of group delay circuits and filters do not introduce an inversion or large wide band phase error. Some of the effects of the problem can be removed by installing an automatic compensation circuit – but this probably does not monitor beyond the line/base station interface equipment. Therefore care is required in the installation and maintenance of the transmitters. For a diagrammatic explanation of 'line reversal' see Further Reading paragraph 9.1.

Later use of an audio 'carrier and sideband' technique (generated by a balanced modulator) was used over land-line circuits to overcome the problems of line reversals. Here the phase of the sideband content when compared to the (e.g.) 2970Hz carrier was always the same at the demodulator as the modulator, no matter whether the line had been reversed or not. Usually detection of the audio carrier frequency was also used for transmitter keying. However this technique may not compensate for reversals in the Line / Transmitter interface.

e. Amplitude Variation.

The amplitude of the audio signals being applied to the transmitter modulation circuits have a direct bearing on the modulation levels and hence on any multi-path 'mixing' process in the mobile receiver. Modern (digital) connections supplied by the telephone/line companies have improved the reliability of the connection; however, not only is the audio delay variable, the audio level delivered to the base station is also variable. It is therefore important to maintain commonality of amplitude at the transmitter input.

5.3 Audio Path Selection - Voting

Voting, par-se, is not a taxing issue with modern equipment, both RSSI voters and Signal/Noise (sometimes referred to as End of Line) voters produce a set of 'best' criteria which are used in the selection process. However the selection process itself will have various functional features available for configuration by the installer. These features may include: -

- i A method of configuring the sensitivity of the selection – i.e. If many 'good' signals arrive it is probably not important which is selected, however if many 'poor' signals arrive it is necessary to select the best of a bad bunch.
- ii A method of configuring what difference in level is required before a change is made.
- iii A method of configuring the speed at which the process switches from one path to another.
- iv Setting of the effect of no incoming signals, is the last path held open or is it closed.
- v The ability to inhibit and or force the selection of a specific path.
- vi An output to indicate that a signal is being received.

These configurable parameters will be used as appropriate to the installation. e.g. If data are being received then it may be desirable not to change the selection once it had been made; or, if the incoming signal is encrypted then there may be a preamble which is affected by the link establishment time; etc.

6 FEATURES OF A SYSTEM

6.1 Essential.

- i Maintenance of the relative carrier frequencies.
- ii A method of measuring and adjusting the audio delay, line 'polarity' and audio amplitude.
- iii Careful choice of transmitter locations and radiation patterns, and adjustment of power levels to tailor the overlap areas between transmitters – to avoid equal-signal overlap wherever possible between just two transmitters (considered to be the worst case for reception at a mobile).

6.2 Desirable.

- i Reliable maintenance free frequency control/generation.
- ii An ability to 'offset' the carrier frequency of a selected transmitter is useful in the elimination of standing waves and attendant signal nulls. This is particularly necessary on low frequency systems in rural areas to prevent stationary mobiles being sat in a signal null.
- iii Automatic response to changes in audio delay.
- iv An ability to 'offset' the delay over a selected line/link. This is a useful method of 'moving' the locus of audio phase matching to correspond with the areas of equal RF signal.

v Automatic compensation of line reversal.
vi Automatic compensation of line amplitude variation.
vii A voter – with sufficient configurable parameters as are required by the system.
viii A supervision facility to evoke an alarm and enable engineering access remotely.

7 DALMAN'S CONTRIBUTION TO YOUR SIMULTANEOUS BROADCAST SYSTEM

7.1 Maintaining base transmitter frequency.

The SATSYNC range of GPS based products features both Frequency Generators and GPS Receivers suitable for use in Synchronous systems as transmitter references and drivers.

7.2 Maintaining audio parameters, voting and engineering access..

COSMOS 4 is fully integrated line interface system, offering all the essential, and many of the desirable, features required in a Synchronous system. The equipment has been designed to reduce the maintenance effort required to keep a Synchronous system in top line condition.

Features include: -

i Manual or Automatic Bulk Delay Adjustment.
ii Remote manual or Automatic line reversal compensation.
iii Remote Station line input sensitivity adjustment (maintaining audio amplitude).
iv RSSI Voting or outputs to an external End of Line voter.
v Central Engineering Access to all sites.
vi Station Environment I/O. etc.,

All integrated in to one set of equipment. This equipment uses the same GPS Receiver (from 7.1 above) to recover timing synchronization signals which are used to reference the delay measurements. The system is a complete line interface and audio conditioning system – only the Base Station RF and Control Room (Dispatcher) equipments are required.

7.3 Product Data

Can be found on the web-site at http://www.dalmants.co.uk.

8 ACKNOWLEDGEMENTS AND FURTHER READING

8.1 Acknowledgements

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8.2 Further Reading

"Simulcasting Without (Too Many) Tears" – Update of a paper presented by R. Atack at the 1989 APCO Conference in Sparks, Nevada
(Available on the web: - http://quasi-sync.atackscomputers.co.uk)

"Simulcast Audio Synchronization" (a lighter weight discussion, for a heavyweight discussion see "Simulcasting Without (Too Many) Tears" by R. Atack, as listed above),
File SimulcastAudioSynchronization.doc* Dalman Technical Services Ltd.

Adjustment of Audio Compensation, Cosmos4 – Technical Publications Book 1 Section 8.
File 10800_18.doc* Issue 3+ Dalman Technical Services Ltd.

* The 2 files marked with an asterisk are available as *.pdf on the web at http://www.dalmants.co.uk.

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