TAG McLaren audio

hi-performance hi-fidelity

Tuner AvantGarde T32R

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1 INTRODUCTION

TAG McLaren Audio's three band tuner has been considered for many years as a standard for high-fidelity radio reception, producing a sound quality almost too good for some of today's radio broadcasts. But if live concerts are to be heard in an amazingly realistic concert-hall ambience, with the most subtle sounds clearly distinguishable, a TAG McLaren tuner was one of the very few capable of delivering it.

The challenge was to build on the TAG McLaren Audio T20 tuner's performance, and to expand well beyond it - a task considered by many as almost impossible at this time because the major broadcasters have just announced the discontinuation of analog radio in a little more than a decade. Whilst the remaining period of continued analog radio is quite long, it clearly declared that any analog tuner will become an obsolete component, hence maybe not worth investing in.

Bearing this conflict in mind the engineering team were tasked to design a tuner suitable for today and tomorrow, a tuner which would bridge the gap between analog and digital radio reception, without compromising on either.

2 THE TARGET

After intense brainstorming the following key features for the new tuner were laid down:

- FM, MW and LW analog reception.
- Sound quality better than T20.
- Full RDS (Radio Data System) functionality without affecting sound quality.
- High-performance DAB (Digital Audio Broadcasting) expansion.
- Future-proof DAB implementation to cope with possible amendments and updates to this new technology.
- User friendly and fully embedded DAB functionality, with DAB presented to the user as another frequency band.
- DAB module to be from a manufacturer well known for its products and qualities having demonstrated a clear vision and recognition of the long term importance of digital services and open to cooperation to optimise the DAB sound quality and functionality.
- Built-in expandability to cater for more sophisticated future digital services (like still picture transmission) as and when available.
- Display consisting of a large, easily read alphanumeric section (key information, such as station name) and a smaller graphical section (details such as RDS or DAB information).
- Full remote control.
- Combined access to cable transmission and outdoor antenna for FM.
- Prepared for multi-room technology.
- Integration in a home cinema package.

3 THE DESIGN RESOURCES

When reflecting on this list of key requirements it became obvious that such a sophisticated and highly ergonomic design needed a rather large design team, consisting of industrial, electronics, RF, PCB and mechanical engineers and many software engineers. The high demand on software resources, being almost 50% of the design team, was initially surprising. However, DAB, RDS, multi-room capability, remote control and ergonomic integration into an overall home entertainment package are predominantly software driven requirements.

> Digital broadcasting (DAB), radio data system (RDS), multi-room capability, remote control and ergonomic integration into an overall home entertainment package are predominantly software driven.

The need for substantial software development lead to the decision to develop the hardware in TAG McLaren Audio and the software in TAG McLaren's automotive division TAG Electronic Systems, with overall project responsibility remaining with TAG McLaren Audio. An added benefit was that this meant software would be developed in accordance with the stringent international quality standard TickIT[1)]. The benefits for the customer were fast time to market combined with very high quality.

The project was named "Tuner AvantGarde T32R" and started in September 1998.

4 DESIGN PHILOSOPHY

Drawing on TAG McLaren Audio's heritage of digital and analog audio design coupled with TAG Electronic Systems' experience of automotive electronic, telemetry and software design, the T32R was in an ideal position to benefit from a wealth of accumulated design experience.

Utilising techniques more commonly seen in professional high quality communication receivers, such as dual 'IF' (Intermediate Frequency) conversion, the T32R has been designed to provide class leading performance.

Many of the techniques developed for the F3 Series pre and power amplifiers have been applied to the analog amplification and filtering stages of the T32R to provide consistently high audio quality. One example is TAG McLaren Audio's straight line technology, others are discussed below.

> Combining RF, digital and analog audio and software engineering disciplines, the T32R demanded a wide ranging design resource, building on many years of accumulated knowledge and experience within the TAG McLaren group.

1) TickIT is a specialisation of ISO 9001 with respect to software quality. To quote the BSI: "By implementing a quality system and gaining certification, an organisation is demonstrating management's commitment to quality and is sending a clear signal to users and competitors that the delivery of quality is a principal management objective. The TickIT logo indicates that the certificated organisation is involved in software development and that TickIT guidance and certification procedures have been followed."
As of 19.1.99, TAG Electronic Systems is one of only 1542 organisations world wide that have attained the level of quality required by, and become certified with, TickIT.

Although FM encoding has significant advantages over AM for high fidelity music reproduction, the T32R has had extensive design effort applied to the AM section so as to extract the very best performance possible from this transmission system.

With the advent of the new DAB transmission format many of the techniques for obtaining the ultimate sound quality from digital media, developed for our range of F3 Series digital products, have been translated to the audio conversion of the received DAB digital data. One example is the use of clock regeneration circuits to minimise jitter on the digital audio clock signals. This ensures that the audio signal produced by the T32R from DAB stations will be as close as possible to the original transmitted signal.

> The use of a powerful 16-bit microcontroller coupled with the inclusion of re-programmable FLASH memory and the TAGtronic™ Communications Bus ensure that the T32R is field ungradable and ready for the future.

5 FUTURE PROOF

The need to support both old and new radio formats (FM, MW, LW and DAB) together with the increasing data decoding requirements for DAB and RDS, necessitated the use of a powerful, flexible microprocessor.

The chosen processor was the Siemens C161RI microcontroller. Devices from this family of microcontrollers have been used within all of TAG McLaren's Formula One powertrain control systems and are now being used in all of TAG McLaren Audio's new range of products. The C161RI is responsible for all the control functions of the T32R (responding to the remote control, selecting the waveband, controlling the frequency, generating the display messages etc). The power of the C161RI, combined with good software and interface design, results in a powerful yet very user friendly product.

All of the T32R software is kept in a single, re-programmable, FLASH memory device. The FLASH memory can be reprogrammed using a PC connected via the TAGtronic™ Communication Bus[2]. This allows the T32R to be upgraded to support new features by a software download without having to open the unit. These upgrades can be performed in the field so that the unit need not be returned to TAG McLaren Audio's factory. Software upgrades will be available via the TAG McLaren web site[3].

6 DIGITAL AUDIO BROADCASTING

With the recent advent of DAB and the planned demise of traditional analog radio broadcasts within the next 10 to 15 years it seemed that any new tuner would have to have DAB or at least be capable of being upgraded to receive DAB. The DAB section of the T32R is on a separate daughter board, interfacing between the main PCB and the DAB front end module. This daughter board not only makes the fitting of DAB at a later date an easy option, but also allows flexibility for the future - as DAB is such a young

[2] Another spin-off from the automotive division where the capacity for so called "end of line" and field upgrade has been a technical requirement for many years.

[3] http://www.tagmclarenaudio.com

technology, any advances could be incorporated into a new daughter card or an upgraded DAB front end (or both) for future expansion.

6.1 DAB history

DAB began life in 1981 at the Institut für Rundfunktechnik (IRT), and since 1987 has been under the banner of a Europe-wide development initiative, the Eureka programme, with the DAB project becoming known as Eureka 147. This project involved a consortium of broadcasters, manufacturers and research institutes collaborating to develop the DAB specification.

DAB's immunity to multi-path and other interferences results in a robust transmission format offering crystal clear reception with no background noise.

In 1994 the specification was standardised by the European Telecommunications Standards Institute (ETSI 300-401), and was ratified as a world standard in 1995.

6.2 Transmission format

DAB is transmitted using a technique known as Coded Orthogonal Frequency Division Multiplexing (COFDM). This essentially involves splitting the signal into a number of separate parts and transmitting it on a group of low data rate carrier frequencies (up to 1536 over a 1.5 MHz wide band), spreading the audio or data signal equally over a number of channels. The benefit of this method of transmitting data is the system's immunity to multi-path interference, which in alternative transmission formats would result in severe loss of data. Being digital data as opposed to analog signals, complex error correction codes and advanced decoding techniques ensure that the data integrity is retained even in poor signal conditions.

6.3 DAB data rates

A DAB single multiplex contains many DAB radio stations combined into one block, with the overall data rate being 1.7 Mbit/s. The number of stations within a multiplex will determine the maximum data rate available for each station. The multiplex is flexible however, so some stations (such as news programmes) may get transmitted with lower data rates (and hence lower sound quality), while others (such as classical concerts) may get transmitted with higher data rates.
The standard data rate from a stereo CD is 1.4 Mbit/s. However, using the MPEG Audio Layer 2 compression algorithm (as used in DAB), field studies with data rates of 192 kBit/s have shown barely discernable differences between the compressed and original audio data. This is now the most common transmission data rate for DAB audio programmes.

When comparing a DAB with an analog radio transmission particular care needs to be taken to not confuse sound limitations caused by the technology with the broadcaster's choice of lower data rates (quantity instead of quality) and applied dynamic compression.

7 T32R TECHNOLOGY OVERVIEW

Being a complex product, the T32R consists of many parts which make the whole. At the nerve centre is the microcontroller section, which controls all the other individual sections and interfaces to the user via the front panel display and keypad. The FM and AM sections provide the analog radio functions while the DAB section provides the new digital radio functions.

The following paragraphs describe the sections in greater detail.

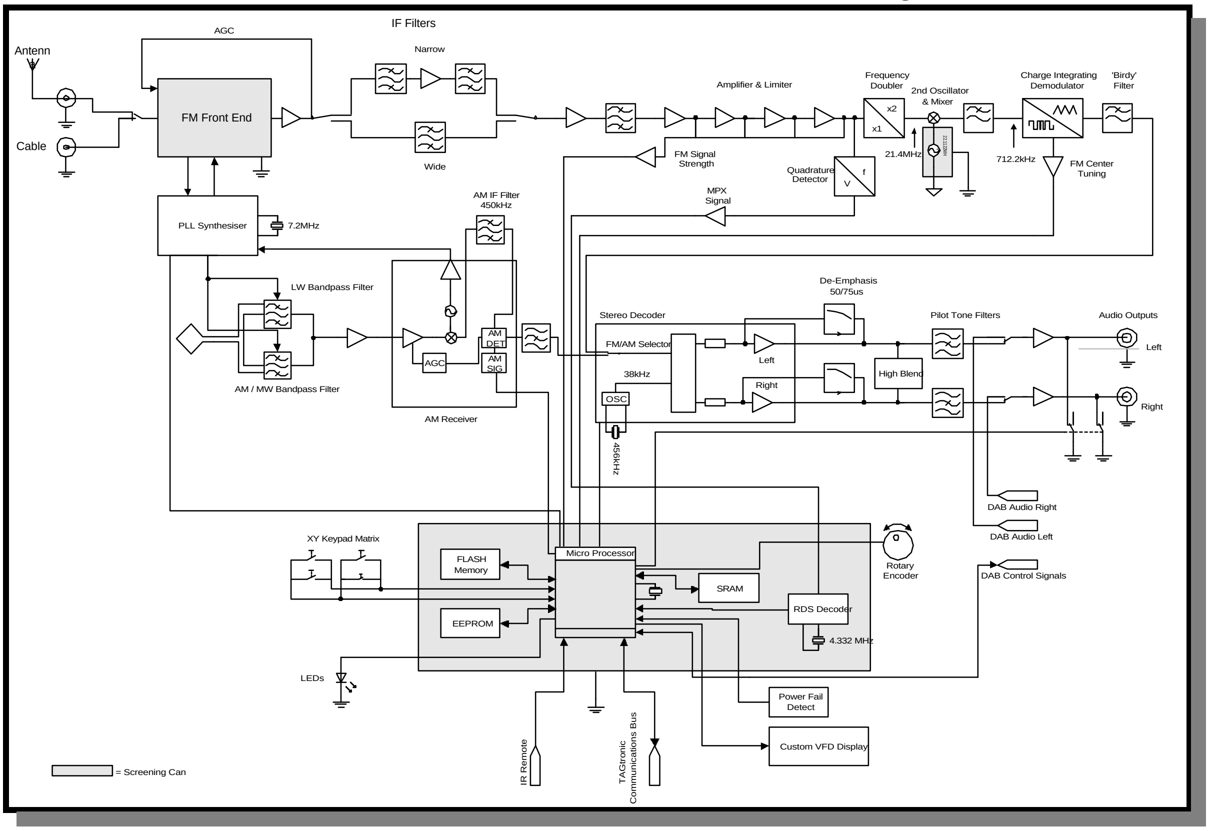
8 FM SECTION

8.1 FM front end

Differences in the radiated power and distance of individual transmitters mean the tuner is faced with the task of handling incoming signals as low as 2 µV and as high as 30 mV. This represents a range of more than 80 dB and requires an FM front end with wide dynamic range and low noise.

The fundamental importance of the front end module to the overall performance of the complete tuner was fully understood. The FM front end for the 8000T and T20 is designed and manufactured in-house. This gives complete control over the design, but the

Tuner AvantGarde T32R Schematic Block Diagram



build, alignment and tuning of the custom front end is very labour intensive.

Based on this experience of FM front end design and manufacture, we decided to adopt an alternative approach for the T32R. Rather than design another custom front end the decision was taken to base the front end design, if at all possible, around a suitable module, which we would then customise to meet all of our high performance standards.

Many potential modules were looked at, several selected and countless comparative listening tests were made between a modified T20 (including the module under evaluation) and a standard unit. After many hours of work, modification and improvement a module from Mitsumi was selected.

Mitsumi is an acknowledged world leader in high quality modules for hi-fi tuners. They build many FM modules each year to exacting standards on fully automated production lines. Their use of precise, large scale automation equipment in the manufacture of these modules together with the years of focussed development spent by Mitsumi ensure that every front end module for the T32R will be perfectly set up on arrival at our factory and require no fine tuning. This will ensure a quality level matching our own front end design but at a lower cost, a direct benefit for our customers.

The Mitsumi front end comprises a varicap tuned RF amplifier, a mixer and a varicap tuned local oscillator. The RF amplifier covers the frequency range 87.5 - 108 MHz (other frequencies may apply for markets outside Europe) while the combination of mixer and local oscillator converts the input RF signal to a 10.7 MHz IF (modulated with 75 kHz peak deviation). The tuning voltage for the varicap diodes in the Mitsumi front end is provided by the T32R's phase locked loop (PLL) circuit. Accurate frequency lock is achieved by using a sample of the Mitsumi front end's local oscillator signal to complete the closed loop PLL circuit.

To improve on the high specification of the Mitsumi front-end module TAG McLaren's AGC (automatic gain control) circuit was added to enable the front end module to cope with both extremely weak and strong received signals. An additional level of RF screening was also incorporated to improve the overall sensitivity of the T32R.

The AGC circuit employs a continuously variable PIN diode attenuator as the first stage in the front-end. This attenuator is controlled by a voltage derived from a rectified signal extracted from the 1st IF filter buffer amplifier. When the IF signal reaches a preset level the attenuator begins to reduce the signal reaching the 1st RF amplifier thus preventing overload and maintaining the resulting IF signal levels well within the linear regions of the IF amplifiers.

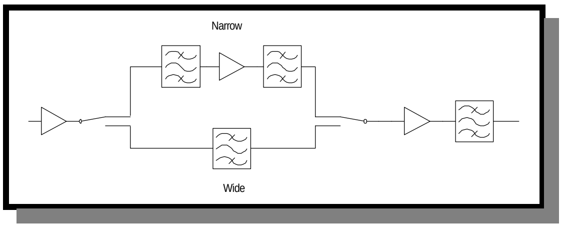
The AGC dynamic range allows the RF module to handle antenna signals up to tens of millivolts.

8.2 IF filtering concepts

FM stations supplying audio programmes to the public are confined to transmitting on carrier frequencies located within a 20.5 MHz band. In Europe this band extends from 87.5 to 108 MHz. At any given location transmitter frequencies should be separated by 400 kHz within this frequency range. This allows a maximum of 50 stations to be transmitted in any particular location.

Not all RF environments are this precisely controlled and often at the boundaries of regions or across borders it is possible for stations to have just 200 kHz separation.

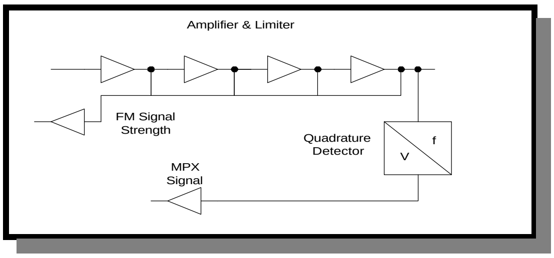
To achieve low distortion and high stereo separation in situations of good reception and yet have a product that is sufficiently versatile to operate in a crowded spectrum it is necessary to provide switchable IF filtering.



In ‘wide’ mode a Gaussian (flat group delay) filter provides minimum distortion with moderate selectivity. In situations where greater selectivity is required the 'narrow' mode selects an alternate filter path employing a two section Butterworth (maximally flat) filter.

8.3 First IF amplifier and limiter

Following narrow or wide-band filtering as appropriate, the 10.7 MHz carrier carrying all the information as frequency modulation with 75 kHz peak deviation is now processed through a four stage amplifier / limiter. This ensures that all amplitude modulation of the carrier is suppressed.



The amount of limiting applied, combined with the AGC at the RF front end, provides an accurate indication of the received signal strength. This is fed to an analog to digital converter onboard the microcontroller, which provides a display of the received signal strength on the custom Vacuum Fluorescent Display (VFD).

The limiting amplifier is followed by a quadrature demodulator which produces a stereo multiplex output. The multiplex signal is fed to the RDS decoder IC via a buffer amplifier which isolates the RDS chip from the multiplex output and thus prevents the RDS system from affecting the audio quality. Although the multiplex signal could already be passed to the stereo decoder to provide left and right audio signals, the quality would be some 30 dB worse in both noise and distortion than the target figures. Instead, the IF signal is passed on for further processing to recover the multiplex signal by a high linearity low noise demodulator.

8.4 RDS

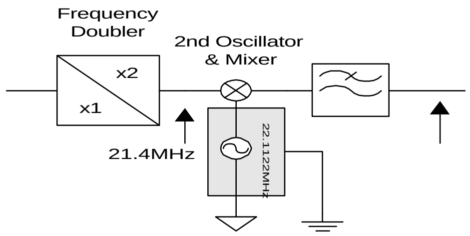
The FM multiplex signal fed to the RDS decoder contains both audio and RDS information. It is the function of the RDS decoder to extract the RDS data from this signal and then pass this information to the microcontroller. The RDS data is modulated onto a 57 kHz sub-carrier within the signal, with a maximum data rate of 1187.5 bits per second. To extract this data the RDS decoder uses a 57 kHz, 8th order band pass filter to eliminate all but the wanted data before demodulating the incoming data stream.

RDS greatly increases the ease of use of the tuner T32R. Extreme precautions have been taken to ensure that this digital RDS signal does not interfere with the received audio signal in any way.

The RDS decoder incorporates a full RDS preprocessor and error correction system ensuring error free RDS data is available to the microcontroller with minimal processing overhead.

8.5 Frequency doubling and dual conversion

Having shifted the wanted station's signal, which was somewhere between 87.5 and 108 MHz with 75 kHz peak deviation, down to a fixed 10.7 MHz carrier with 75 kHz deviation, the modulation index has improved by a factor of approximately 10. Increasing the modulation index has the benefit that a potential improvement in demodulated signal to noise ratio is now on offer.

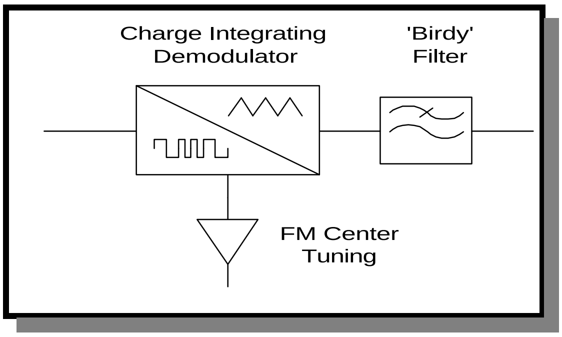


The next step is to frequency double the IF signal to 21.4 MHz with 150 kHz peak deviation. To achieve this the modulated 10.7 MHz IF is used to drive a pair of transistors in push pull with common collectors connected to a 21.4 MHz tuned load. The resulting signal is applied to one port of a J-FET mixer, the other port is driven by a 22.1122 MHz crystal controlled, ultra low noise oscillator. The mixer output contains the wanted difference frequency of 712.2 kHz and an unwanted sum frequency of 43.5122 MHz. The latter component is removed by a 7 pole low pass filter which is -3 dB at 3 MHz.

8.6 Charge integrating demodulator

The desired audio information is still encoded by frequency modulation of a 712.2 kHz carrier with 150 kHz peak deviation. The modulation index has increased again (times 12). The modulated signal is next used to switch a push pull transistor pair which controls a pair of constant current sources and sinks. This charges a voltage clamped capacitor with a constant current at variable time periods. This fixed charge but with variable mark space ratio is then applied to a high speed wide-band integrator. This approach achieves exceptional linearity (less than 0.01 % - 80 dB THD) and low noise (approaching - 90 dB in mono) without adjustment, drift or microphony, resulting in an unchallenged performance.

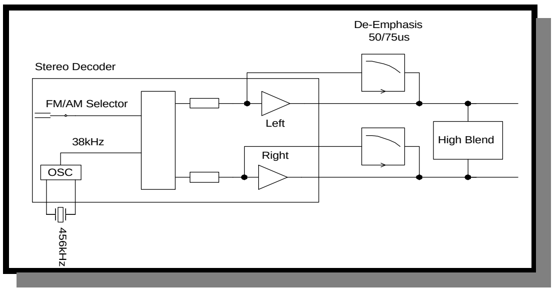
The modulated sawtooth waveform is then passed through a nine section low pass Butterworth filter which is - 3 dB at 100 kHz. This filter is carefully calculated for the optimum group delay, low in-band ripple and high stop-band attenuation which helps to eliminate the 3rd (114 kHz) and 5th (190 kHz)



harmonics of the 38 kHz suppressed sub carrier of the encoded multiplexed stereo audio. These harmonics, if passed unchecked, are notorious for producing beat interference with adjacent channels which manifest themselves as unwanted tones or 'birdies'.

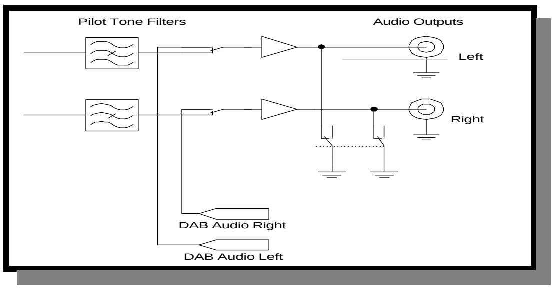
8.7 Stereo decoder

The demodulated signal is now processed by a phase locked loop controlled stereo decoder. Excellent separation (50 dB at 1 kHz), low noise (< -80 dB mono, < -75 dB stereo) and low distortion (<0.08 % THD stereo) characterise this item. It provides pilot tone cancellation to reduce in-band intermodulation products. When used in conjunction with subsequent filtering it results in vanishingly small remnants of multiplex pilot tones whose presence can otherwise lead to a degradation in sound quality.



8.8 Analog filtering

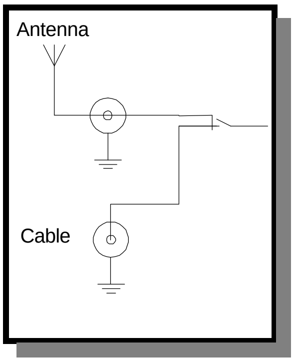
Multi-pole filters, tuned to 19 and 38 kHz, are used to achieve the superlative pilot tone rejection figures of >80 dB at 19 kHz. Accurate source and load impedances are presented to these filters to ensure precise passband performance. These filters are buffered by the direct coupled, servo controlled, low output impedance (100 Ω) line level amplifiers.



The analog stages, from the frequency to voltage demodulator, use precision, metal film, Vishay resistors. For ultimate fidelity muting is controlled by a relay which mutes the signal by shunting to 0 V to avoid relay contacts in the signal path.

Inter-station audio level reduction of -20 dB is switched in when tuning across the spectrum with the muting function off to reduce the level of irritating off-station 'hiss'.

8.9 Multiple FM antenna inputs



To enable FM stations to be received from either an external antenna or a cable feed, two antenna connections have been provided. The FM AGC automatically caters for the nominally higher strength signal associated with direct cable feeds, reducing them to a more suitable level for the T32R's FM front end.

9 DIGITAL AUDIO BROADCASTING

9.1 DAB coverage

With DAB being a relatively new broadcasting format, the first question many people will ask before contemplating the purchase of a DAB receiver is "Can I receive DAB where I live?".

While it is beyond the scope of this paper to predict the precise coverage of DAB at any given location, it is fair to say that DAB transmissions already cover a significant percentage of the population in Europe and are continuously increasing.

The following list illustrates the DAB coverage by percentage population in Europe in May 1999:

- Sweden 85%
- Belgium 83%
- UK 60%
- Italy 60%
- Portugal 50%
- Holland 45%
- Norway 35%
- Germany 30%

9.2 User Friendliness through full user interface integration

While DAB is a completely new broadcasting format, it is essential that the first-time user can easily operate it without having to be a technophile. The T32R handles DAB just like another "radio band" offering additional programmes and services. With this in mind the T32R's user interface has four band selections: FM, MW, LW and DAB, each selectable by a single button push.

9.3 DAB functionality backed-up by FM

If the DAB signal is lost the T32R will automatically switch to the equivalent station on FM (if available), based on a cross-reference list the tuner has established (the required information for this change-over is transmitted along with the DAB transmissions and memorised by the T32R for later use).

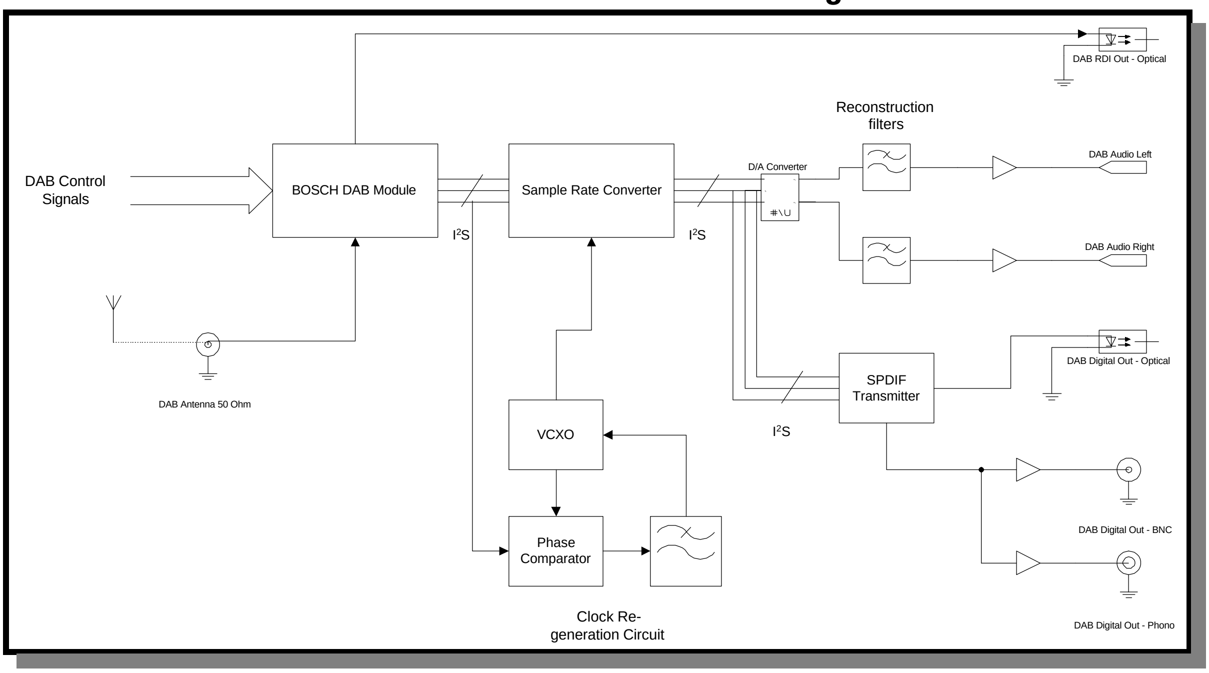
9.4 DAB receiver module

TAG McLaren Audio have worked in close co-operation with Bosch Multimedia Systems to seamlessly integrate their latest DAB receiver module into the T32R. As a direct result of this collaboration, modifications to the DAB receiver software have been engineered by Bosch to TAG McLaren Audio's requirements, providing a unique level of performance from the module, tailored specifically for the T32R. The DAB receiver module is capable of receiving DAB transmissions on both band III (174 MHz - 240 MHz) and L-band (1452 MHz - 1492 MHz) using a common 50 Ω antenna input. It supports DAB modes I, II, III and IV according to ETS 300 401.

The receiver features high selectivity due to its use of a high order recursive digital filter. The

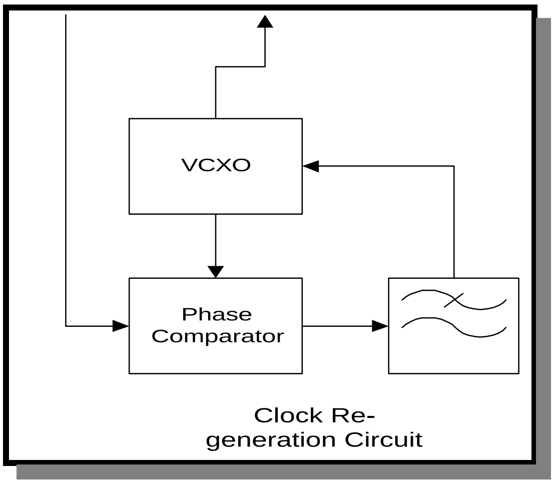
> Bosch's name is synonymous with quality and high performance, attributes which perfectly suit TAG McLaren's reputation. TAG McLaren Audio feels honoured to share with Bosch the determination to provide the best DAB tuner available in the market.
>
> The choice of Bosch as our partner in the development of the T32R's DAB option gave TAG McLaren Audio access to the latest DAB technology from a key player in this new technology.

T32R DAB card schematic block diagram



module will follow dynamic DAB multiplex re-configuration without muting the selected programme in one block.

The DAB full accuracy audio decoder (equivalent to ISO MPEG 1.2 Layer II) is implemented according to ISO/IEC 11172-4 (MPEG 1) and 13818-4 (MPEG 2). The decoder supports the full sampling rate of 48 kHz and half sampling rate of 24 kHz. Dynamic Range control (DRC) is implemented according to ETS 300 401 and can be enabled / disabled by the user.



9.5 Jitter

One of the principle causes of distortion in a digital audio product is jitter. Jitter is a distortion caused by errors in the timing of digital audio signals. Data dependant timing errors are one of the most audible and unpleasant types of jitter, so it is essential to remove these.

The T32R uses a crystal-based phase locked loop design to reduce the jitter on the master clock to an absolute minimum. This phase locked loop is based upon a voltage controlled crystal oscillator which provides one of the most stable clock oscillators possible. The phase locked loop filter starts to reject jitter from the clock signal at 6 Hz and it is critically damped to provide good stability and excellent lock time.

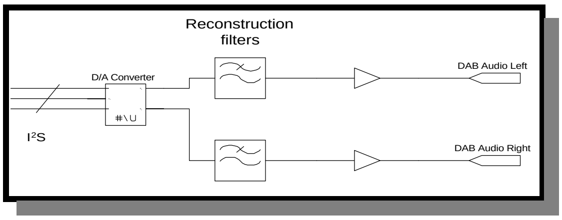
Careful circuit design, layout and electrical noise suppression experience gathered in F1 racing by TAG McLaren's automotive division have created a system in which the clock design is optimised in all respects for low jitter response.

9.6 The DAC topology

To achieve the best possible sound from the DAC, the quantisation noise present on the output has to be filtered out. This is performed by a combination of a 128 times over-sampling filter within the DAC itself and an external analog filter.

The requirements on the analog filter are greatly relaxed due to the over-sampling. However, listening tests proved that it still had a significant impact on sound quality. The design was optimised to produce a filter which has very low group delay within and beyond the audible frequency range. The low group delay reduces the phase error between low frequency and high frequency sounds.

After considerable optimisation by measurement and listening, a fourth order Linear Phase filter with equi-ripple phase accurate to better than 0.5^{o} was selected. This type of filter has a flat group delay extending past the transition region and is thus ideal for filtering audio signals. Using a fourth order filter, rather than the second order filter used in most designs, means the high frequency noise at the output is considerably lower. Reducing this noise reduces the possibility of distortion due to intermodulation in subsequent amplifiers and thus improves the focus and detail of the sound.



The filter is implemented using high quality, low distortion operational amplifiers (op-amps) from Burr Brown. They were selected after considerable measurement and listening and are used throughout TAG McLaren Audio's product range to give a consistently high level of performance. These op-amps, combined with high quality passive components (Vishay resistors and Wima Capacitors), create a very transparent output path which allows every nuance of the sound and the true depth of the bass to be revealed with complete clarity.

9.7 Digital outputs

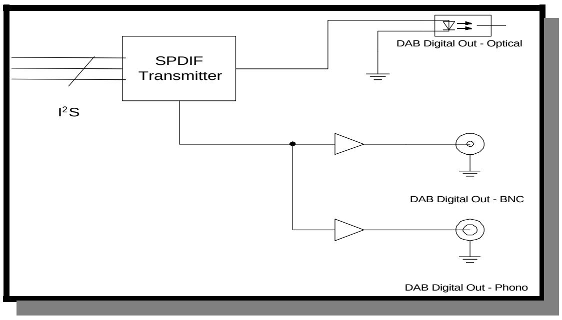
Within the T32R the DAB data stream is converted to high quality analog audio through a combination of carefully controlled processes. However, with the increasing abundance of digital audio systems in the home environment some may prefer direct access to this digital data for subsequent processing (either recording digitally or using external D/A converters, for example). To facilitate this the T32R provides the re-clocked digital audio data output in SPDIF format; both optical (TOSLINK™ connection) and electrical (phono and BNC connections).

The DAB specification allows for broadcasters to transmit DAB using either full sample rate (48 kHz) or half sample rate (24 kHz). The benefit of the lower sample rate to broadcasters being the opportunity to fit more stations within their allotted bandwidth.

This poses a potential problem when feeding the DAB digital audio stream to external devices, the majority of which cannot accept 24 kHz sample rates, preferring the standard 48 kHz rate. To alleviate this problem, the T32R contains a sample rate up-converter, internally converting the 24 kHz digital audio data to 48 kHz, prior to making this data available to external devices.

> DAB allows broadcasters to transmit either full sample rate (48 kHz) or half sample rate (24 kHz) data. The half sample rate poses a potential problem when feeding external da converters as the majority cannot process it.
>
> The T32R contains a sample rate up-converter, converting 24 kHz to 48 kHz, prior to making this data available at its digital outputs.

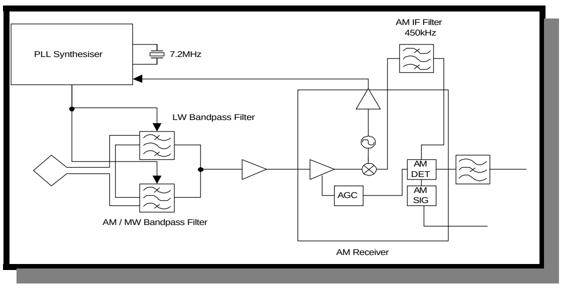
In addition to the digital audio data the T32R provides a Receiver Data Interface (RDI) connection. The data brought out to this connector (TOSLINK™ optical) contains the entire data stream from the selected sub-channel of the DAB multiplex. This data stream contains the audio data plus additional Programme Associated Data (PAD) such as accompanying text and pictures. To make use of this data an optional, external decoder will be required.



10 AM SECTION

A single, high Q, low resistance loop antenna is tuned across the MW and LW frequency bands by means of a phase locked loop synthesiser. The antenna can additionally be complemented with a long-wire external antenna for reception in remote or heavily screened areas.

Separate filters, tailored to the step sizes, are used for MW and LW. The AM signal demodulation is performed by an integrated AM receiver with AGC control of the RF amplifier.



The mixer is driven by an automatic, level-controlled oscillator and the local oscillator output to the synthesiser is buffered to avoid strong signal interference (using a similar technique to the FM RF stage).

A 4 pole ceramic filter operating on the IF (450 kHz) passband is used to provide high adjacent channel selectivity > 45 dB. The AGC controlled IF amplifier in turn feeds the AM (envelope) detector. The AM AGC is low-pass filtered to avoid strong signal boosting of low frequency audio signals. The AM detector drives the AM signal strength monitoring circuit which feeds back to the microcontroller for display.

An AM audio notch filter removes high level alternate channel high frequency noise and beat notes above 4.5 kHz. Passband filtering provides two different audio passband responses of 45 Hz - 1.5 kHz (narrow) and 45 Hz - 4.5 kHz (wide).

The buffered IF output is fed to the frequency synthesiser where frequency counting circuits are included to interface with the T32R's auto-tuning system.

11 MICROCONTROLLER SECTION

11.1 Non volatile memory

A serial EEPROM is used for pre-set and last station memory. This non-volatile memory results in the unit returning to the last setting and memorising all presets no matter how long the unit is removed from mains supply. The T32R has 99 preset stations which can be assigned to any waveband. Each preset will also store the setup data of the selected station, for example IF bandwidth, stereo mode etc.

11.2 Screening

To prevent any of the high speed digital signals from the microcontroller section interfering with the RF and audio sections, a screening can has been placed over the microcontroller and digital section of the printed circuit board. Input and output lines to this section are decoupled to prevent digital noise causing degradation in the analog circuitry. To further protect the weak RF signals entering the T32R, a screening can has also been placed over the FM front end section.

11.3 Signal level monitoring

A four channel Analog to Digital converter onboard the microcontroller is used for measuring FM signal strength, AM signal strength, FM centre tuning and the AGC compensation of the FM front end. This digitised data is then formatted by the microcontroller and is output to the custom designed VFD for display.

11.4 Tuning

The auto-tuning, scan up and scan down features of the T32R provide excellent ergonomic control for selection of desired stations. The sophisticated phase locked loop synthesiser provides the data required for accurate and precise auto-tuning independent of the IF bandwidth for either AM or FM reception. A requirement for the T32R was that it should provide the best aspects of both automated scan and manual tuning. The resolution of the synthesiser on the FM band allows for 25 kHz steps. This is very much narrower than the wide, low group delay, IF filters used for low colouration reception. If the station sensing was performed on the presence or absence of signal strength alone the auto-tune facility would not stop on centre tune. This synthesiser is designed to eliminate this problem by using a secondary process whereby a count of the IF frequency is performed. If the frequency does not exactly match either 10.7 MHz (FM) or 450 kHz (AM) a signal is returned to the microcontroller instructing a further step to be taken, followed by a recount, until the exact IF frequency is achieved.

12 BEST SOUND QUALITY

12.1 The design principle

The topology and devices used to achieve the excellent sound quality of the T32R were selected after constructing and evaluating many prototypes. Each prototype underwent extensive listening tests to fine tune and compare the options. The final sound characteristics were optimised by cross-referencing with experience built up over thousands of hours listening to and improving TAG McLaren Audio products.

12.2 The components

The dependence of sound quality on the parasitic parameters of electronic components is well known and widely recognised. TAG McLaren Audio's extensive listening tests have resulted in the use of high quality Elna Cerafine bulk decoupling capacitors in the audio power supplies, ultra stable Vishay metal film resistors and low dielectric loss Wima polypropylene capacitors in the audio signal path, beside many carefully selected integrated circuits from several manufacturers.

12.3 The power supplies

The analog and digital sections have separate power supplies to reduce interference between them. To maintain separation of the different sections within the unit, the T32R uses 10 individually regulated linear supplies in all. Each is optimised using the best type of capacitor decoupling for its function and appropriate noise suppression filtering.

A higher 12 V supply rail for the output stages gives increased head-room and improved driving of cables.

To maintain separation of the different sections within the unit, the T32R uses 10 individually regulated linear supplies in all. Each is optimised using the best type of capacitor decoupling for its function and appropriate noise suppression filtering.

The transformer used within the T32R is of toroidal construction as this has the benefit of a very low stray magnetic field, reducing the possibility of interference with the audio signals. The transformer is inherently very quiet, reducing hum to an inaudible level.

Not content with the already low magnetic leakage of standard toroidal transformers, the transformer used within the T32R is custom designed incorporating three layers of magnetic GOSS (**G**rain **O**riented **S**ilicon **S**teel) shielding to reduce stray magnetic fields to an absolute minimum.

12.4 Mixed technology

Within the digital region it is very important to control the high speed currents drawn by the digital IC's. This control is achieved using surface mounted, ceramic chip capacitors which can be located very close to the digital components. Being close to the IC's they can supply the required currents with the minimum of interference to the rest of the board.

The analog region required a different approach, using surface mounted, high speed capacitors near the output filter components, combined with a three level scheme of bulk decoupling. This consists of bulk decoupling using large, high quality Cerafine storage capacitors near the linear regulators, slightly smaller high quality storage capacitors by each of the sensitive components and surface mounted Polymer Electrolytic Neocaps very close to the supply pins. The Neocaps have a cathode conductance 100 times that of an ordinary tantalum capacitor and 1,000 times that of a Aluminium Electrolytic capacitor, this gives a greatly improved high frequency response. This three level approach is used for all of the sensitive audio components. By using these combined methods all of the power delivery problems within the system are addressed to deliver fine detail and stable images, as well as powerful but controlled bass response.

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12.5 Multilayer technology

The layout of the printed circuit board can have as much effect on the performance and sonic quality of a product as can the choice of components and circuit design. Careful layout of the circuit board to separate the RF, analog, digital and power supply sections of the T32R has helped to minimise crosstalk and distortion on all signals producing a cleaner, richer sound.

Multilayer circuit boards are used in the T32R to control the complex pattern of return currents from each of the different functional circuit blocks, provide controlled impedances for the high speed digital signals and minimise coupling between signal traces.

> Careful attention to PCB layout and ground plane separation enables the T32R to reject unwanted digital or RF signals, resulting in a cleaner, purer sound.

The T32R has a complex power distribution system using an entire layer of the PCB. Power distribution is optimised through the use of very low impedance solid planes. This optimisation reduces distortion in the analog region and improves the digital signal characteristics and electro magnetic compatibility of the complete T32R.

Within the analog audio and RF regions it is important that the very sensitive, high resolution signals are not disturbed by the return currents from the high speed digital processing circuits. Separate ground planes are used under the analog, RF and digital regions to provide low impedance return paths for the currents. To minimise crosstalk and noise, the ground planes are split along the boundaries between the analog, RF and digital processing circuits.

Multilayer circuit boards are virtually essential if effective planes are to be created. Attempting to create planes using conventional two layer circuit technology inevitably leads to compromises with many ground return current paths having to be constructed out of relatively fine tracks in congested parts of the circuit, resulting in higher impedances and greater crosstalk between power and signal traces. Avoiding this compromise reduces digital noise emissions and significantly reduces the effects of the bass return currents on the high frequency treble components. This improves both the bass transient response and the image stability.

At the very high switching speeds of the digital circuitry the PCB tracks have transmission line characteristics. Multilayer boards, combined with precise control of track dimensions, spacing and layout, are essential to present these digital signals with well-defined, consistent impedances. This, together with correct signal termination, ensures that the signals are not corrupted by reflections and crosstalk. This is particularly critical for the clock signals, where the multilayer board is an essential element in achieving extremely low jitter levels.

The multiple layers of the PCB and the planes within it allow significant reductions in crosstalk to be achieved by routing signals perpendicular to one another on different layers and screened from one another by the ground planes.

A further benefit of the use of multi-layer circuit boards is the ability to increase component density. This leads to shorter tracks and smaller signal loop areas, which in turn reduces sensitivity to external interference and reduces noise emissions.

The advantages of a multilayer PCB construction meant that, despite its relatively high cost, it was the only logical choice to maintain the exceptional level of performance required from the T32R.

13 FUTURE PROOF THROUGH THE TAGtronic™ COMMUNICATION BUS

The T32R features the TAGtronic™ Communication Bus. This allows TAG McLaren Audio units to work seamlessly together to form an effective, integrated system. Remote control codes can be transferred over the bus, allowing system components to be operated out of sight. The TAGtronic™ Bus will allow the system to be extended to offer multi-room capability in which the output from sources can be controlled and redirected throughout the home.

> The user can program the T32R to wake up from low power standby at a given time. Similarly the T32R can be programmed to switch into standby mode after a predetermined time - the snooze mode. The world's best sounding alarm clock?

The bus communications protocols are compatible with standard PC asynchronous serial links (RS-232). The electrical interface is RS-485, selected because of its use of balanced signals, its suitability for long cable runs and its ability to function in a multi-drop mode (allowing many units to be connected in parallel). Using balanced signals addresses grounding issues in complex systems, serving to eliminate potentially troublesome sources of hum. RS-485 can be converted to the PC standard RS-232 using a simple adaptor.

> The T32R can be upgraded via the Internet, using a PC and a suitable connection cable.

The T32R can be upgraded via the Internet, using a PC and a suitable connection cable.

14 TIMER FUNCTIONS FOR CONVENIENCE

The T32R can extract real time clock information from FM stations transmitting RDS information. With this clock information, the T32R can be programmed to wake up from low power standby at a given time. Similarly the T32R can be programmed to switch into standby mode after a predetermined time interval - the snooze mode.

The potential obviously exists for a power cut to cause the T32R to lose its clock time. However, the T32R is clever enough to recognise this; as soon as power is restored, the T32R will switch to the most recently used FM station transmitting RDS to update its internal clock. Being mindful that this may be in the middle of the night, it will keep all of its outputs muted. Once the clock time has been updated, the T32R will switch back into standby mode, ready to wake up at its predetermined time.

If a suitable FM station carrying RDS clock time information cannot be found, the T32R will try the DAB band (if available) as an alternative source to update its internal clock. The T32R will always use the RDS clock time in preference to DAB clock time. This is because DAB suffers from encoding and decoding delays during the transmission process, hence resulting in a minor inaccuracy of the received clock time.

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15 TACTILE FEEDBACK: THE ROTARY ENCODER

With the advent of the digitally controlled, synthesised tuner, manual tuning generally became controlled by momentary action pushbuttons which resulted in the clumsy and often slow process of stepping the frequency synthesiser at a rate determined by the microcontroller. In the T32R the flywheel action of a manually adjusted, ganged capacitor tuned receiver has been recreated through the proprietary design of a dedicated, optically coupled, incremental encoder, which incorporates magnetic detents to indicate the frequency step action.

Integrated with the system software, the rotary encoder can mimic the old tuning mechanisms as above, but also has an automatic compensating mode. This mode senses when you are spinning the tuning knob faster and adjusts the incremental steps accordingly, which helps you to tune faster from one end of the scale to the other. When the tuning knob is rotated slowly, the T32R detects this and readjusts the incremental steps to a finer resolution allowing more accurate tuning.

16 REMOTE CONTROL

The T32R comes with a system-controlling remote. In addition to duplicating the buttons found on the front panel of the T32R, the remote control includes buttons to access the menu structure and timer functions.

To simplify band selection there are individual buttons for each waveband. Additional mode control buttons are provided to allow the user to fully control the T32R without scrolling through lists or using complicated two button procedures. All the most commonly used features on the T32R are available with a single button press.

17 THE POWER USER

17.1 Customising the T32R

Users who prefer a customised look and feel can take advantage of a comprehensive menu programming system accessible from the remote control. The menu system allows the user to customise the screen layout and tuning parameters to meet their individual preferences. Once set, these preferences will be memorised by the T32R, even after power to the unit has been removed.

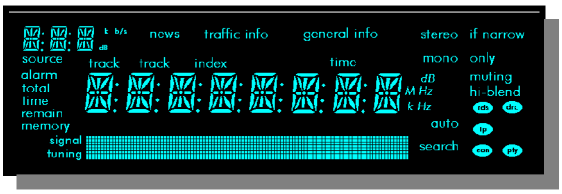
It is not essential to be familiar with this functionality to operate the T32R in its entirety. The function is added for people you like to customise their products heavily.

17.2 400Hz Calibration tone

To assist in setting up recording levels a 400 Hz calibration tone, corresponding to 37.5 kHz deviation in FM mode and 50% modulation in AM mode, has been provided.

18 DISPLAY TECHNOLOGY

With the advent of RDS and now DAB the display requirements for a tuner far exceed those of earlier analog tuners. To cater for these new requirements TAG McLaren Audio designed a custom VFD offering high contrast ratios with an intuitive and flexible layout.



The custom display incorporates a dot matrix area for radio text messages and a larger 8 digit alphanumeric area for station names and tuning frequencies. Not content with the poor legibility of the standard "starburst" display, TAG McLaren Audio re-designed this font from first principles culminating in the TAG McLaren 'Dot Burst' font. This substantially increases the legibility of the display.

19 FOR THE BEST DISPLAY TECHNOLOGY: THE T32R INTEGRATES INTO A HOME CINEMA SET-UP

Utilising the TAGtronic™ Bus, the T32R can pass radio data information decoded from RDS and DAB transmissions to externally connected units. One such unit is the TAG McLaren Audio theatre AV32R surround sound processor, which has the ability to display radio text messages from the T32R tuner on a television screen with its "on screen display" technology.

> The T32R can display RDS and DAB text on a television via the AV32R. This allows many exciting combinations, such as overlaying travel information or the result of a football match over a soap opera. Finally, radio is integrated in home cinema.

An additional feature that can be exploited with DAB data is to use a PC connected to the TAGtronic™ Bus to display images accompanying an audio transmission.

20 MANUFACTURING

For best results the surface mount components on the T32R are placed and soldered by TAG McLaren's automotive division in Woking, using high precision placement robots (accuracy better than 80 µm) and an inert gas (nitrogen) infra-red re-flow oven. Soldering in a nitrogen atmosphere results in significantly higher quality solder joints than conventional atmospheric processing.

After re-flow soldering the boards are cleaned and shipped to Huntingdon where all leaded components are fitted and the printed circuit board is wave soldered. After wave soldering, component values and tolerances are checked by an automatic roving probe tester. The tested printed circuit boards are then installed in the case together with the remaining components, such as the transformer, switches, connectors etc. Finally, a full performance test of the completed T32R is conducted to verify perfect operation. The tested T32R is then thoroughly cleaned before being packed and sealed with its accessories by operators wearing lint-free anti-static gloves. The sealed package is only opened by the final owner.

21 CONCLUSION AND OUTLOOK

The T32R is an exceptional quality analog and digital tuner which has been designed to meet the needs of the user now and in the future. It can be combined perfectly with TAG McLaren Audio's existing range of high-quality pre-amplifiers and amplifiers, uniquely complementing its exemplary sound quality.

Using the TAGtronic™ Communication Bus the T32R is able to communicate with other TAG McLaren Audio products, making remote and multi-room installations a reality.

Tuner T32R

Full Specifications And Measured Performance

FM Section	
Tuning range	87.5 MHz - 108.0 MHz (E/N/UK)
Tuning steps	25 kHz (manual)
	50 kHz (scan) (E/UK)
	100 kHz (scan) (N)
Intermediate frequencies	10.7 MHz, 21.4 MHz and 712.2 kHz
Sensitivity	4.0 dBµV pd (or 15.2 dBf) - (IHF useable) mono
	8.0 dBµV pd (or 19.2 dBf) - (IHF 50 dB) mono
	30 dBµV pd (or 41 dBf) - (IHF 50 dB) stereo
Frequency response (± 1 dB)	5 Hz - 15 kHz
Ultimate signal to noise ratio	greater than 80 dB (for greater than 46 dBµV or 57 dBf) (mono)
	greater than 75 dB (for greater than 64 dBµV or 75 dBf) (stereo)
Selectivity	greater than 65 dB (IF narrow) - (IHF alternate channel)
	greater than 40 dB (IF wide) - (IHF alternate channel)
	greater than 10 dB (IF narrow) - (IHF adjacent channel)
	greater than 4 dB (wide) - (IHF adjacent channel)
Stereo separation	50 dB (at 1 kHz)
Total harmonic distortion (at 1 kHz)	less than 0.05% - (mono, IF wide)
	less than 0.08% - (stereo, IF wide)
	less than 0.2% - (mono, IF narrow)
	less than 0.2% - (stereo, IF narrow)

Tuner T32R

Full Specifications And Measured Performance

Capture ratio	less than 1 dB (IF wide) - (IHF 40 kHz deviation)
	less than 2 dB (IF narrow) - (IHF 40 kHz deviation)
Spurious response	greater than 70 dB - (IHF image)
	greater than 80 dB - (half IF)
	greater than 80 dB (IF)
	greater than 70 dB (others)
AM Suppression	greater than 60 dB (IHF)
Pilot tone rejection (19 kHz)	greater than 80 dB
Channel imbalance	less than 0.5 dB
Calibration level (-6 dB peak level)	37.5 kHz deviation
De-emphasis	50 µs or 75 µs according to country
Antenna connections	antenna 75 Ω (unbalanced)
	cable 75 Ω (unbalanced)

MW Section	
Tuning range	531 kHz - 1602 kHz (E/UK)
	530 kHz - 1710 kHz (N)
Tuning steps	9 kHz (manual / scan) (E/UK)
	10 kHz (manual / scan) (N)
Intermediate frequency	450 kHz
Sensitivity	600 µV.m^{-1} (for 20 dB signal to noise)
Selectivity	greater than 50 dB ± 9 kHz (± 10 kHz, N)

Tuner T32R Full Specifications And Measured Performance	
	greater than 75 dB ± 18 kHz (± 20 kHz, N)
Total harmonic distortion	less than 0.3% (30% modulation) (50 Hz - 4 kHz)
	less than 1.0% (100% modulation) (50 Hz - 4 kHz)
Ultimate signal to noise	greater than 54 dB
Spurious response	greater than 40 dB (image)
	greater than 50 dB (IF)
Frequency response (± 1 dB)	45 Hz - 4.5 kHz (IF wide)
	45 Hz - 1.5 kHz (IF narrow)
Calibration level (-6 dB peak level)	50% modulation

LW Section	
Tuning range	144 kHz - 288 kHz (E/UK)
Tuning steps	1 kHz (manual)
	9 kHz (scan)
Intermediate frequency	450 kHz
Sensitivity	800 µV.m^{-1} (for 20 dB signal to noise)
Selectivity	greater than 50 dB ± 9 kHz
	greater than 75 dB ± 18 kHz
Total harmonic distortion	less than 0.3% (30% modulation) (50 Hz - 4 kHz)
	less than 1.0% (100% modulation) (50 Hz - 4 kHz)
Ultimate signal to noise	greater than 54 dB
Spurious response	greater than 40 dB (image)

Tuner T32R

Full Specifications And Measured Performance

	greater than 50 dB (IF)
Frequency response (± 1 dB)	45 Hz - 4.5 kHz (IF wide)
	45 Hz - 1.5 kHz (IF narrow)
Calibration level (-6 dB peak level)	50% modulation

DAB Section	
Tuning range	1452 MHz - 1492 MHz (L band)
	174 MHz - 240 MHz (band III)
Sensitivity	BER[4] $\leq 1\text{x}10^{-4}$ for $P_{in} \geq -92$ dBm (L band)
	BER $\leq 1\text{x}10^{-4}$ for $P_{in} \geq -91$ dBm (band III)
Large signal behaviour	BER $\leq 1\text{x}10^{-4}$ for $P_{in} \leq -15$ dBm (L band)
	BER $\leq 1\text{x}10^{-4}$ for $P_{in} \leq 0$ dBm (band III)
DAB modes supported	mode I, II, III, IV (ETS 300 401)
Data converter	24 bit, 48 kHz and 24 kHz, 128 times oversampling, multi-bit delta sigma DAC
Antenna connection	50 Ω BNC unbalanced

General Specifications	
Tuning accuracy (FM / AM)	± 0.001%
Calibration frequency	400 Hz
Audio output impedance	100 Ω nominal

4) Assuming code rate ½, Gaussian channel, BER is residual bit error rate, i.e. after convolutional decoding.

Tuner T32R

Full Specifications And Measured Performance

Output level (full modulation)	1.55 V rms
Audio output connector	phono sockets
Digital outputs	coaxial SPDIF, phono socket
	coaxial SPDIF, BNC socket
	optical EIAJ RC-5720, TOSLINK™
Data output	optical EIAJ RC-5720, TOSLINK™
Digital output impedance	75 Ω ±10%
Digital output level (into rated load)	500 mV pp ±10% (75 Ω load)
Operating temperature range	10 - 35°C
Power consumption	less than 35 W
	less than 5 W (standby mode)
AC Supply frequency	50 - 60 Hz
AC Supply voltage	110 - 120 V (N) or 220 - 240 V (E/UK)
Physical dimensions (incl. feet, terminals and controls)	445 mm wide
	75 mm high
	338 mm deep
Weight (excluding packaging)	less than 7 kg

(N), North America
(UK), United Kingdom
(E), Europe