Smart AM Receivers for the 21st Century

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Abstract - *Currently available AM receivers in automobiles and for home and portable use incorporate narrow RF and audio bandwidths to counter the increasing noise environment caused by man-made RF interference sources, such as power lines with ill-maintained insulators and transformers; overhead cable TV and DSL services; fluorescent lamp ballasts; computer modems; and LED traffic lights and household lights, to name a few. By utilizing currently available software-defined radio design techniques, coupled with CQUAM AM stereo technology, this paper will address the design and features of a new smart AM receiver that will serve to restore listenership to the AM band. Audio examples will be included in the presentation.*

OVERVIEW

AM radio constitutes the most bandwidth-efficient broadcast medium and provides an essential service to many Americans, particularly in rural and remote areas, and those traveling in the vast expanses of this nation. AM radio, due to its generally lower capital requirements, can also provide a realistic setting for family-based, community-focused station programming and ownership, especially in smaller localities. AM radio is truly a national resource, a source of unique voices, and particularly in light of its unique propagation characteristics has tremendous reach, especially in times of local, regional, and even national emergencies [1]**.**

Fundamentally, the two greatest issues currently threatening AM radio are: **(1)** the worsening electromagnetic environment; and **(2)** the concurrent failure of the consumer-products industry to provide the listening public with high-quality AM receiver systems (comparable to their FM counterparts). It has been all too easy for the receiver manufacturers to simply reduce overall receiver bandwidths down to even 2-3 kHz to address the pervasive issues of electromagnetic interference (EMI) noise from power lines, fluorescent-lamp ballasts, personal computers, consumer devices, and the like, not to mention broadband static impulses from lightning and increased adjacent-channel and alternate-channel interference from more recently allocated AM stations. Another factor in the lack of receiver bandwidth is the inability of radio manufacturers to obtain decently matched low-cost varactor tuning diodes to provide the required tracking accuracy for the simultaneous electronic tuning of the AM RF front-end, mixer, and local-oscillator stages in their receivers (both home *and* auto). Added on top of all this is the progressive trend in the automobile industry to replace metal body parts with plastic (which worsens EMI shielding), adopt windshield-type antennas (which provide markedly poorer reception performance for both AM and even FM), and add a multitude of noise-generating microcomputers for engine control, antiskid braking systems, and the like. The net result has been AM radios with low (and ever declining) audio and reception quality.

It is thus imperative to the sustainability of AM radio that the FCC strongly encourage (or even mandate) significant improvement in consumer AM systems. Without this the American listening public will continue to regard AM as a noisy, low-fidelity medium and will consequently tune out. Without advanced consumer-receiver features to address the severe noise, interference, and bandwidth challenges to good, clean AM-band reception, the appeal of AM to the public will inevitably be lost.

The technical goals of vastly-improved consumer AM receivers are actually near at hand. The great majority of the required receiver functions are already offered by international chip manufacturers such as Silicon Labs (Austin, TX), NXP Semiconductor (Netherlands), ST Microelectronics (Switzerland), and Frontier Silicon (U.K.) in their advanced software-defined radio (SDR) AM/FM chip products. For example, it is now possible to offer agile, programmable channel bandwidths and audio high-cut filters [to address the increased levels of nighttime and critical-hours sky-wave adjacent-channel interference (ACI)], noise limiters, and adaptive RF/IF AGC functions. A few U.S.-specific enhancements such as adaptive notch filters at 10 kHz could be easily added.

BACKGROUND

We acknowledge the FCC's past leadership role in the overall thrust to improve AM radio, beginning in the 1989-1991 period. It is our view that the FCC in large measure did its job well with the establishment of wider-bandwidth, consistent AM transmitter performance, reduction of mutual broadcast interference, and the encouragement of the production of better receiver hardware by the consumer-electronics industry. Initially the consumer manufacturers made a concerted attempt to specify performance of AM receivers through the 1993 AMAX standard, a joint effort of the EIA and the NAB, with FCC backing. In that standard, the desirability for higher receiver bandwidths and noise performance was broadly acknowledged, with the purpose to restore the reception of high-quality AM signals to the public. An AMAX-certified receiver had at least 7.5-kHz bandwidth for home and auto versions, and 6.5-kHz for portables, plus some form of bandwidth control, either automatic or at least two manual settings (e.g., “narrow” and “wide”). It also had to meet NRSC receiver standards for distortion, de-emphasis, effective noise blanking, and include provisions for an external antenna and coverage of the Expanded AM band. The FCC rapidly followed up on this with codification of the CQUAM AM stereo standard, also in 1993. At this point, the stage appeared to be set for rejuvenation of the AM band. Nevertheless, with the legacy of confusion and disappointment in the rollout of the multiple incompatible AM stereo systems, and failure of the manufacturers (including the auto makers) to effectively promote AMAX radios, coupled with the ever-increasing background of noise in the band, the general public soon lost interest and moved on to other media.

It appears at this point (2015), the FCC has a fundamental choice for AM radio: either take a firmer hand in pushing new, improved receiver technology implementations, or permit AM to spiral downward into a slow, painful death. The legal precedent for the former is quite strong. In the early 1960s, the UHF television band was close to economic extinction, as very few TV receivers were equipped with UHF tuners. This was a problem at the time since the major TV networks were well established on VHF, while many local-only stations on UHF were struggling for survival. As a result, the **All-Channel Receiver Act** was passed by the United States Congress in 1961, to allow the FCC to require that all television set manufacturers include UHF tuners. Specifically, the Act provided that the FCC would "have authority to require that apparatus designed to receive television pictures broadcast simultaneously with sound be capable of adequately receiving all frequencies allocated by the FCC for television broadcasting." Under authority provided by the All-Channel Receiver Act, the FCC also adopted a number of technical standards to increase parity between the UHF and VHF television services, including a 14-dB maximum UHF noise figure for television receivers [2].

The original UHF tuner improvements mandated by the All-Channel Receiver Act represented a relatively small cost increment for the TV sets of the day; similarly, with modern high-volume chip technology, the needed signal-processing features for the AM-side of modern receivers can be added for a few dollars at most.

Clearly, automobiles are the prime venue; home hi-fi systems and portables will undoubtedly follow. Further, it would seem logical that all HD Radios also be upgraded on analog AM; with the greater processing complexity of these premium units, the additional cost on a per-unit basis to augment them would be negligible. If Congressional action is actually deemed necessary to enable all the requisite steps in AM revitalization to occur, it is encouraging to remember that the CALM Act was very recently passed to address a far less significant public issue (loud TV commercials!).

It would seem that due to the huge receiver disparity, AM radio is now in a similar situation, which must be remedied very soon. The fundamental solutions for AM are strikingly similar to those of UHF-TV; ***receiver parity with the dominant FM band must be established to enable the public to make listening choices on a more level playing field.*** This critical *receiver* audio bandwidth issue is depicted in Figure 1 below.

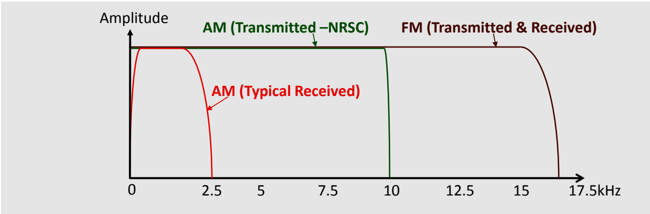

FIGURE 1 – FM VS. AM AUDIO FREQUENCY RESPONSE

The ***transmitted*** bandwidth for FM is about 15 kHz, while the corresponding AM systems handle up to 10 kHz – a very respectable figure. As can be seen from the figure, not only are virtually all AM ***receivers*** limited to about a 2.5-kHz response on the high end, but are also rolled-off in the bass to reduce the effects of the all-too-frequent interference from power lines and other AM-band EMI sources. Thus, compared with FM, with its full audio bandwidth and stereo imaging, AM sounds dull, thin, flat, and noisy. The result is a staggering disadvantage to AM stations, especially on music programming, which must be corrected as soon as possible.

THE AM NOISE ISSUE

The gradual growth of EMI from electric power lines (at all voltage levels), telephone and cable lines, and a variety of consumer devices has been a tremendous detriment to AM broadcast reception. Part 15 of the FCC Rules sets quite reasonable limits for both conducted and radiated emissions, both within the AM band and elsewhere. Although AM-band emissions are especially problematic to broadcasters, out-of-band radiation can also affect amateur radio operations, and other communications users; such illegal emissions are rightfully deemed "harmful interference" and have been universally understood as such in the communications field. The proliferation of bad high-voltage line insulators, transformer bushings, transient protectors, and line/ground connections, has led to broad degradation in AM radio reception, particularly since in most cases power lines follow roads.

Although electric utilities are the most common offenders in this regard, telephone and cable firms also have caused problems, usually due to DSL and other forms of signal leakage. Most current AM radios are quite susceptible to the resulting impulse-type noise. Once this raucous "buzz" even temporarily overwhelms the radio, the listener is strongly prompted to switch to FM or another programming source. We submit that the FCC must protect the public interest, along with its licensed broadcasters, by aggressively enforcing its own Regulations. Closer to home, many existing radios, TVs, consumer devices (e.g., CD players), computers, MP3 players, and such, emit very high levels of local RFI produced by internal clock circuits, RF synthesizers, microprocessors, and the like. Poor unit design (including lack of effective shielding) thus impairs or even precludes nearby AM radio reception. Common problems with FCC Laboratory Type-Accepted, Verified, or Certified devices for consumers could be resolved, with some extra effort, through existing regulatory channels. Numerous internationally marketed products (from radios to fluorescent ballasts and LED drivers) with RF power-line filters for EU countries, when sold in the U.S. have filter components missing, in clear violation of Part 15 Rules. This major problem should be soluble through concerted FCC action, particularly on resellers. As a direct result, the AM broadcast medium will be afforded some critical relief to reception noise and coverage issues. ***Major FCC Part-15 enforcement action here is absolutely vital.***

Obviously, before we can correct the bandwidth deficiencies of AM radios, we must vigorously address the handling of environmental noise, both natural ***and*** man-made. Most of the required techniques have existed for many decades in military and amateur receivers [3], and were optimized in CQUAM AM stereo receiver chips designed and sold by Motorola, Sprague, and others in the mid-1990s, but have been largely neglected until recently.

Fundamentally, the effective rejection of AM-band RFI requires a distributed, multi-stage noise-limiting approach, including: **(1)** antenna/front-end fast clamping; **(2)** a triggered blanker at the output of the (first) mixer; **(3)** a delayed blanker at the I-F output/detector input; **(4)** a delayed sample-and-hold at the audio output; and **(5)** a variable 10-kHz notch filter to reject adjacent carrier signals; and **(6)** a noise-sensing circuit to achieve the desired system control actions. The Motorola circuits proved very effective in extended field testing at rejecting even very severe RFI noise, while rendering the output audio substantially noise-free. Figure 2 provides a functional diagram of the 3rd-generation CQUAM MC13027/MC13122 receiver chip combo, with key noise-limiting circuits noted in red [4].

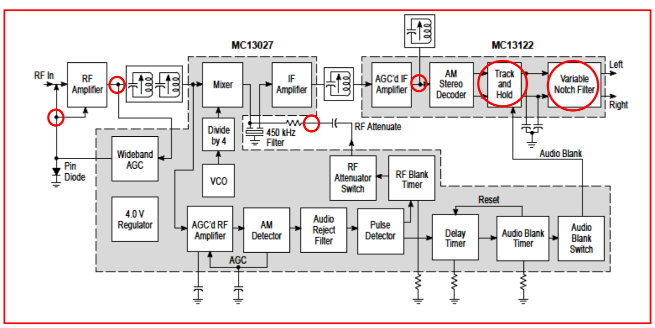

FIGURE 2 – MOTOROLA AM RECEIVER WITH ADVANCED NOISE LIMITING

RECEIVER SPECIFICATIONS

It is essential for the future of AM radio that very close to full parity be established for new AM receivers versus their FM counterparts. This includes: **(1)** low internal noise floor, well below the average AM-band atmospheric noise level; **(2)** high overall RF sensitivity, selectivity, and dynamic range, to provide adequate amplification of weak signals, even in the presence of significant adjacent- and/or alternate-channel signals, especially in strong-signal environments; **(3)** highly effective noise (EMI) rejection, including staged RF and IF noise blanking, accompanied by appropriate audio blanking when required**; (4)** full 10-kHz audio bandwidth capability with low detector distortion, plus dynamic bandwidth control (including adaptive 10 kHz notch filtering) as dictated by noise and adjacent-channel interference; and **(5)** stereo capability (if the receiver has FM stereo capability, it must have CQUAM decoding for AM). Without the first three requirements, basic AM reception will suffer compared with FM; without the last two, the output sound quality cannot be closely competitive with FM. The key suggested receiver specs are summarized below:

Audio Bandwidth: 50 Hz to 9-10 kHz typical, adaptive with a minimum nominal bandwidth of 7.5 kHz; reduced adaptive bandwidth (~ 3-kHz *minimum*) permitted in high noise or adjacent-channel interference situations (i.e., nighttime). Variable-Q notch filter @ 10 kHz standard.

Signal-to-Noise Ratio (Ultimate): minimum 55 dB, preferably ≥ 60 dB.

Sensitivity: -120 dBm (~1 μV) for a signal-to-noise ratio (SNR) of 10 dB.

Selectivity: 25-50 dB (adaptive, using co-, adjacent-and alternate-channel detection).

Dynamic Range: ≥ 100 dB.

Noise Figure: 1 - 3 dB.

Image Rejection: 50 dB or better.

Intermodulation: IP_2, IP_3 intercepts +10 to +40 dBm.

IF: low, with image-rejecting down-conversion or alternatively, double (up-down) conversion.

Stereo Separation: minimum 25 dB, 50 Hz - 10 kHz

Noise limiting: multi-stage, with adaptive timing and performance as per the AMAX standard or better.

The unique nature of the AM broadcast band, in terms of the aliased channel allocation structure, high levels of atmospheric and man-made noise, and propagation characteristics, provides challenges to receiver designers to provide high levels of RF performance in difficult environments at low unit cost. With the advent of advanced, highly integrated radio receiver chips as cited above, many of the needed complex functions can now be implemented at modest cost in the receiver hardware (vehicle or home).

A detailed comparison between high-quality consumer FM receivers and their typical AM counterparts clearly reveals the vast gulf in overall performance between the two bands (see Table I below). The sensitivity, signal-to-noise ratio, dynamic range, noise figure, impulse noise rejection, and almost universal lack of stereo capability are major deficiencies of modern AM receivers; even their inexpensive FM counterparts are far better in almost every respect. Further, the effective adjacent- and alternate-channel rejection figures are much worse for AM units due to the unavoidable sideband-spectrum overlap between close-spaced stations; FM has fewer problems in this regard. FM receivers are also inherently much more resistant to impulse noise, owing both to the amplitude-insensitive nature of the limiter/detector system and the higher carrier frequencies.

Table I – Comparison of FM vs. AM Receiver Specs

Specification	FM (Current)	AM (Current)	Parity?	AM (New)	Parity?
Audio Bandwidth	15 kHz	2.5 kHz	No!	10 kHz	Close
Signal/Noise	65 dB	35 dB	No!	55 dB	Close
Sensitivity (20 db SNR)	2 µV	500 µV	No!	20 µV	Close
Selectivity (Adj./Alt.)	45/60 dB	40/50 dB	Close	40/50 dB (Adaptive)	Yes
Dynamic Range & Intercepts	100 dB	70 dB/ 0-10 dBm	No!	100 dB/ +10-40 dBm	Yes
NF/Noise Rejection	3/50 dB	14/20 dB	No!	2-3/50 dB	Yes
Image Rejection	60 dB	30-40 dB	Close	50 dB/50 dB	Yes
Stereo Separation	35 dB	------	No!	25-30 dB	Yes
Antenna	E-field (Fair)	E-field (Poor)	No!	H-field/ Diversity	Yes

From the fourth column in Table I above, it is acutely clear that effective receiver parity between the two bands does not exist in currently produced models. The suggested specs for a next-generation AM unit in the fifth column would provide for reception and sound quality closely competitive with those of FM. Key to this is the ability of AM audio to be on a par with FM for music as well as news/talk programming. Smart adaptive gain, bandwidth, noise rejection, and selectivity characteristics would permit the listener to have similar experiences with both bands, assuring the longevity of the AM radio industry.

Illustrating this advanced adaptive behavior, the receiver response is shown in Figures 3-7 at 4 different signal levels: **(1)** Close-in [10 mV/m]; **(2)** Suburban [2 mV/m]; **(3)** Fringe [0.5 mV/m]; and **(4)** Nighttime [2 mV/m]. The receiver's response is dependent on relative carrier and modulation levels, including on-frequency, adjacent, and alternate channel signals. Dynamic bandwidth control, interference cancellation, and audio control are performed digitally for higher performance plus lower unit cost/complexity (comparable to HD Radio units).

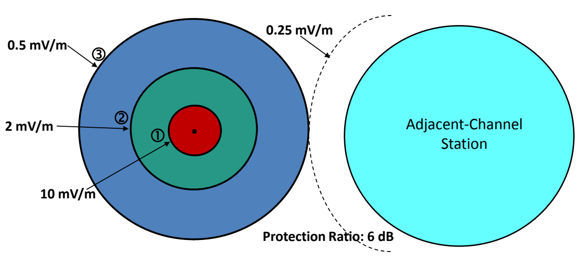

FIGURE 3 – AM RECEPTION CASES

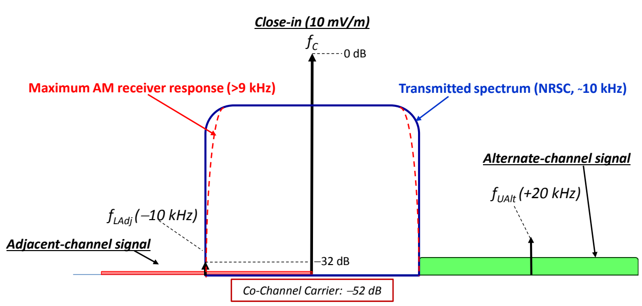

FIGURE 4 - RECEIVER CLOSE-IN FREQUENCY RESPONSE

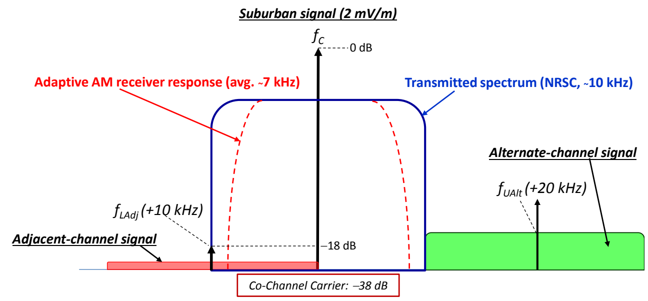

FIGURE 5 - RECEIVER SUBURBAN FREQUENCY RESPONSE

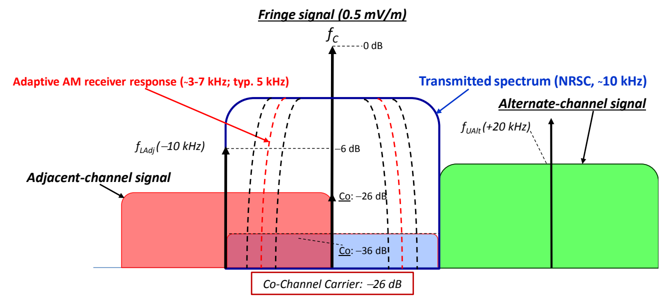

FIGURE 6 - RECEIVER FRINGE FREQUENCY RESPONSE

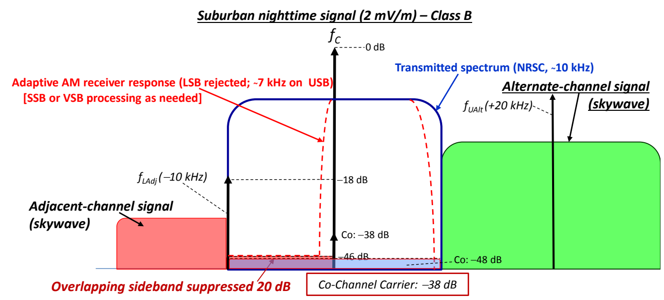

FIGURE 7 - RECEIVER NIGHTTIME FREQUENCY RESPONSE

As can be seen from the plots in Figures 4-6, the adaptive receiver exhibits near-full bandwidth for close-in strong-signal conditions (i.e., 10 mV/m), reduces it slightly under suburban signal levels (~2 mV/m), and draws it in progressively further as the desired signal drops to fringe levels (<1 mV/m). Likewise, noise-limiter thresholds also decrease adaptively to deal with the increased noise. In Figure 7, for nighttime reception in suburban areas, the fully adaptive receiver can utilize single-or vestigial-sideband techniques to more effectively reject the overlapping lower-adjacent interfering signal. These adaptations are dynamic, so the receiver can rapidly adjust to changing signal conditions as needed. Further, the use of optimized synchronous detectors can vastly improve AM sky-wave reception at night by providing a stable local carrier reference during deep selective-fading intervals and thereby eliminating the severe envelope distortion so often encountered . A co-benefit of the proposed wide-scale and/or local synchronization of AM transmitters [5],[6],[7] is that more elaborate signal-processing techniques to optimize overall AM reception can be implemented without having to deal with the constant high-amplitude low-frequency carrier beats. This will yield much smoother, more listenable AM audio in weaker signal areas for the consumer, especially in terms of stereo imaging for music programming.

As stated earlier, several chip manufacturers have in the past few years begun offering numerous very high-performance, highly integrated radio-receiver chips to provide advanced AM/FM processing features with low parts count and moderate cost to the worldwide consumer market. These devices, generally fabricated in modern fast, small-geometry CMOS processes, contain all the basic circuitry to implement a fully optimized, adaptive AM/FM receiver, including: **(1)** front-end preamps; **(2)** advanced AM/FM noise blankers; **(3)** dynamic AM/FM channel bandwidth control; **(4)** AM low-cut filter; **(5)** selectable soft mute; **(6)** advanced stereo blend; **(7)** a programmable suite of signal metrics, including dynamic on-channel, adjacent-, and alternate-channel signal-strength measurements [e.g., RSSI, SNR]; **(8)** onboard frequency synthesizer with fully integrated PLL-VCO local oscillator; **(9)** integrated clock; **(10)** digital low-IF or double-conversion architecture; **(11)** an on-chip AM/FM RF/I-F AGC system with integrated resistor and capacitor banks; and **(12)** a complete digital interface to an associated microcomputer for adaptive, programmable system control [8],[9],[10].

The RF signal-processing architecture basically provides a series of sensors to detect the on-channel and neighboring signals, which are then used to program the receiver's bandwidth and noise-limiting actions and thus automatically optimize the reception of the selected station in an ongoing fashion. These currently available chips already meet the majority of the essential specs for the next-generation AM receiver; with a few additional functions such as CQUAM AM stereo decoding and agile AM signal processing, the required feature suite for full-fidelity AM reception would be complete.

The adoption of these specs for new AM radios will assure excellent performance in both strong-signal and fringe areas, both during daytime and at night, even with significant sky-wave interference. The advanced adaptive receiver features mentioned above, plus others, can be economically implemented using modern DSP-based radio and (optionally) external DSP chips; a typical AM/FM unit block diagram is given in Figure 8.

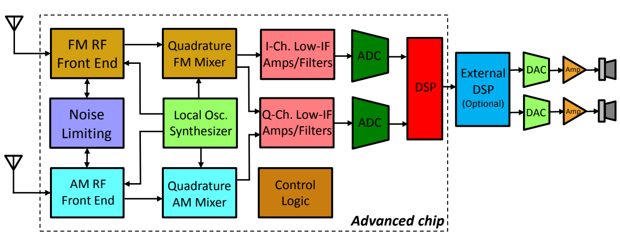

FIGURE 8 – TYPICAL ADVANCED RECEIVER ARCHITECTURE

No discussion of radio receivers should omit the fundamental source of the received signal – the antenna (or, in the case of diversity reception, antennas). As cited previously, the tendency for modern vehicles is for appearance's sake to eliminate the tried-and-true vertical "stalk" antenna, which was quite efficient for FM (at least with vertical transmission polarization) and was generally adequate for decent AM reception. However, with the need for better RF pickup for the AM band and multipath reduction in FM, other antenna configurations should be carefully considered. A shielded loop, for example, permits good magnetic (**H**) field AM signal reception, while screening out much of the local E-field noise from auto electronics and nearby power lines. Loop-antenna units (including ferrite loopsticks) can be fabricated at low cost and mounted in windshields, windows, trim, and under plastic body panels. Further, multiple air-core units, mounted vertically, can be effectively utilized when coupled with standard diversity-combining techniques. These AM loops can be configured for good FM reception as well. Figure 9 below provides an illustration of how such H-field antennas could be incorporated into vehicles at low cost.

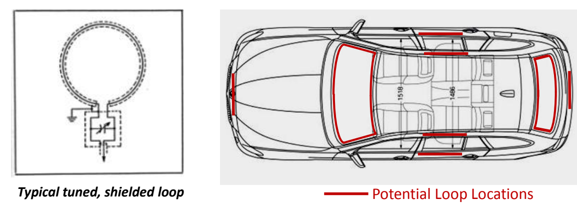

FIGURE 9 – VEHICLE H-FIELD IMPLEMENTATIONS

As can be seen at left, the fundamental element in these antennas is the tuned loop. Obviously, the smart receiver hardware should incorporate appropriate tuning elements such as varactor diodes and associated control circuitry to permit the tracking of the antenna(s) with the selected station's frequency. This would significantly improve sensitivity and simultaneously afford additional selectivity to address close-in stations as well as local RFI sources. With multiple antennas as shown at right, effective diversity schemes for both FM and AM reception could be affordably implemented and provide a significant boost in reception quality in all types of terrain.

CONCLUSIONS

AM radio is a longstanding American institution, a source of unique voices, and one that we can ill afford to abandon. During the recent national disasters, Hurricane Katrina and Superstorm Sandy, AM radio stations proved to be the news source that the public utilized more than any other when telecom and other services were unavailable.

In this paper we have presented the technical specifications and circuit topology for smart AM receivers for the 21st century, which will be characterized by high-fidelity AM stereo reception in today’s difficult noise environment, which in turn will serve to draw listeners back to the AM band and will enable music programming to be restored to this vital local radio service. The state-of-the-art AM receiver features that are addressed in this paper can be largely implemented with off-the-shelf radio receiver chip sets, augmented by advanced software-defined techniques.

Further, these advanced AM receivers will utilize the Motorola-developed (and FCC-sanctioned) C-QUAM compatible stereo technology, which is now non-proprietary due to the expiration of the associated patents. It is the opinion of the authors that the AM receiver technical specifications presented in this paper should be established by the FCC as the minimum acceptable technical standards for any new AM receivers introduced in U.S. retail stores, online outlets or in new automobiles and trucks. These changes, by establishing effective parity with FM, will greatly incentivize the listening public to return to the AM band, via the rapid establishment of noticeably better audio and reception conditions throughout the U.S.

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